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COTTON ROOTROT IN THE SAN ANTONIO ROTATIONS

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INTRODUCTION

The disease known as cotton rootrot has been prevalent on the San Antonio Experiment Farm since cotton experiments were begun there in 1906. It was not, however, until 1912 that definite observations on the occurrence of the disease were made a matter of record. In that year counts were made of the number of cotton plants affected by rootrot in certain plots in a series of crop-rotation experiments, and the proportion of these diseased plants to the total number of plants in the plots was computed. Similar observations have been made each year since 1912, so that with the season just passed there are available eight years' records of the disease in these rotation fields.

In 1916 the disease was so serious that more detailed observations concerning it seemed justified, and at the close of that season each of the cotton plots in the rotation fields was carefully measured and a diagram was made, showing the spots in which the plants were dead from the effects of the disease. Each season since 1916 similar diagrams have been made of each cotton plot.

It has been thought that the best remedy for cotton rootrot was to be sought through a suitable rotation of crops, supplemented by deep plowing and thorough tillage. The rotation experiments here considered include a number of different crop sequences as well as some very different methods of tillage. While these rotation and tillage experiments were not planned with particular reference to rootrot control, they afford an opportunity to observe the reactions of the disease to different treatments during a series of years.

During the eight years of record, 1912 to 1919, the disease has become increasingly serious in these rotation plots, as is shown in Table I, which gives for each year the average percentage of plants killed by rootrot in all the cotton plots in the rotation experiments.[1] There were 25

[1] The actual increase in severity of the disease has been somewhat less than the data here given would indicate, for the reason that prior to 1916 the rootrot counts were made before the end of the growing season. The actual dates on which the counts were made are as follows: 1912, Aug. 13; 1913, Sept. 4; 1914, early September (exact date not recorded); 1915, Sept. 28; 1916, Oct. 23 to 25; 1917, Oct. 25; 1918, Oct. 23 to 29; 1919, Oct. 27 to 31.

cotton plots in 1912 and 30 plots devoted to this crop each year since 1913. Of this number, 4 have been in cotton continuously, 20 have been in cotton each alternate year, 4 have been in cotton every third year, and 2 have been in cotton every fourth year.

The table also gives the average yield of all cotton plots in the rotations in pounds of seed cotton per acre, the total annual precipitation as recorded at the experiment farm, and the precipitation occurring during the crop season each year from April 1 to October 31.

TABLE I.—*Average percentage of cotton plants killed by rootrot in the rotation experiments at San Antonio, Tex., the average yield of these plots in pounds of seed cotton per acre, the total annual precipitation, and the seasonal precipitation, April to October, for the years 1912 to 1919*

	1912	1913	1914	1915	1916	1917	1918	1919
Average percentage of plants killed by rootrot	0.4	1.3	2.0	7.1	21.4	9.7	12.7	26.0
Average yield in pounds of seed cotton per acre	621	560	784	567	430	536	259	42
Total annual precipitation	26.29	36.71	31.37	26.64	27.26	13.22	27.06	47.64
Total seasonal precipitation	11.67	22.77	22.98	21.22	21.47	11.18	19.05	38.12

DESCRIPTION OF THE ROTATIONS

The plots on which these rotation experiments are conducted are ¼ acre in size, being 264 feet long by 41.25 feet wide. The longer dimension of the plots lies on an east and west line, and the alleys between the plots are 4.75 feet wide. When planted to cotton each plot contains 10 rows, 4.1 feet apart. The rotation plots are arranged in two series which extend north and south. Of these series the one on the west is called series A and the one on the east series B. A field road some 20 feet wide runs along the west side of series A, another separates the series from each other, and still another north and south road bounds series B on the east. Each series is subdivided by two crossroads, 16 feet wide, so placed that each subdivision of a series includes 18 quarter-acre plots. The subdivision or field at the north end of each group is numbered 4, the center one is numbered 5, and the one at the south end is numbered 6. Thus, field A–4 lies at the northwest corner of this group of six fields, and field B–6 lies in the southeast corner. The plots in each field are numbered from 1 to 18. The regularity of the system just described is broken in field A–4 by placing 4 plots whose long dimensions lie on a north and south line in the space that should be occupied by the 3 plots, 7, 8, and 9. These 4 plots—numbered 7, 8, 9, and 10, counting from east to west—are each surrounded by a ridge or border to prevent the run-off of water during torrential rains. Consequently there are in field A–4 actually 19 plots instead of 18, as in the other fields.

This detailed description of the location of these field plots is given so that the reader may the better interpret the subsequent notes on the field distribution of the rootrot infection.

It is not necessary for the present purposes to describe all the rotations in the San Antonio series, so that only those including cotton are given in the following list, and only the principal features of the tillage methods preceding the cotton crop are indicated. These cotton rotations may be grouped into four categories, as follows:

1. Cotton continuously:

A–4–19. Cotton following field peas plowed under in March.
A–6–3. Cotton on land plowed in November.
B–5–3. Cotton on land plowed in November.
B–5–4. Cotton on land plowed in November and manured each year at the rate of 16 tons per acre.

2. Cotton on the same land alternate years:

A–4a. Cotton on land plowed in December and fallowed for 16 months.
A–4d. Cotton following corn on land plowed in July and fallowed 8 months.
A–5c1. Cotton following oats on land plowed in June and fallowed 9 months.
A–5c2. Cotton following grain sorghum on land plowed in July and fallowed 8 months.
A–5d1. Cotton following cowpeas plowed under in November after an oat crop maturing in June.
A–5d2. Cotton following grain sorghum on land manured and plowed in July and fallowed 8 months.
A–5e1. Cotton following cowpeas plowed under and the land subsoiled after an oat crop maturing in June.
A–5e2. Cotton following grain sorghum on land manured, plowed, and subsoiled in July, and fallowed 8 months.
B–5a. Cotton on land plowed in November following forage sorghum.
B–5b. Cotton on land plowed in November following forage sorghum.
B–5e. Cotton on land plowed in July following grain sorghum.
B–6a. Cotton on land plowed in July following corn.
B–6b. Cotton on land plowed and subsoiled in July following corn.
B–6c. Cotton on land manured and plowed in July following corn.
B–6d. Cotton on land following corn, manured, planted to field peas, and plowed in March.
B–6e. Cotton following corn, manured, planted to field peas, plowed under in March, and subsoiled after the cotton crop.
B–6f. Cotton following corn on land disked in July after the corn crop but not plowed until after the cotton crop.
B–6g. Cotton on land plowed in February after corn.
B–6h. Cotton on land plowed and subsoiled in February after corn.
B–6i. Cotton following corn with rye disked in after the corn and plowed under in February.

3. Cotton on the same land every third year:

A–5a. Cotton on land plowed in June, fallowed 9 months following oats for hay, which had followed grain sorghum.
A–5b. Same as A–5a, except that the land was manured following the cotton crop.
B–4a. Cotton on land plowed in November following Sudan grass, which in turn followed grain sorghum.
B–4b. Cotton following field peas plowed under in March after oats for hay which followed grain sorghum.

4. Cotton on the same land every fourth year:

A–4f. A rotation of oats for grain, land plowed in June; grain sorghum followed by field peas plowed under in March; forage sorghum, land plowed in November; cotton planted the following April.
A–4g. A rotation that differs from the above only in that the field peas are cut for hay instead of being plowed under.

The plowing in these rotations is ordinarily done to the depth of about 8 inches; where subsoiling is indicated, this is done in each furrow after the plow to the depth of 12 to 14 inches. After plowing, all plots are kept in good tilth and free from weeds by harrowing and disking until the subsequent crop is planted. Where manure is indicated, it is applied at the rate of 16 tons per acre and plowed under.

It will be observed that cotton is the only crop used in these rotations that is subject to rootrot injury and that the diversity of tillage methods fairly well covers the range of farm practice in this region.

In the first of the categories listed above, cotton recurs on the same plot each year. In the second case, cotton recurs on the same plot each alternate year, so that to give an annual expression as to the rootrot injury each rotation may be regarded as occupying a field of ½ acre in size, one-half of which is in cotton each year. Likewise, for the third category, each of the four rotations may be thought of as occupying a plot of ¾ acre in size, of which one-third is in cotton each year, permitting an annual expression of the rootrot injury for each rotation. In the fourth case the rotation would be regarded as covering 1 acre of ground, of which one-quarter is in cotton each year.

This method of comparison is faulty, of course, in that it assumes a degree of uniformity as between adjacent plots with respect to rootrot infection that probably does not exist. But, on the other hand, in view of the fact that the different rotations were located in the fields without previous knowledge as to the location of rootrot areas there was no chance for bias in their distribution. It would be fair to assume that if any system of rotation or any method of tillage were really effective in controlling the disease this effect would be shown by a lower annual percentage of plants dying from the disease within the area subjected to that system or method.

COMPARISON OF THE ROTATIONS

In order to compare the effect of the disease as observed in the different rotation plots, it is necessary to present in some detail the annual records as to the percentage of plants killed by the disease.

In the first of the categories listed above there are four plots on which cotton has been grown continuously during the period of record. The extent of rootrot injury in each of these plots is shown in Table II.

TABLE II.—*Percentage of plants killed by rootrot in the continuously cropped cotton plots at the San Antonio Experiment Farm, 1912 to 1919*

Plot No.	1912	1913	1914	1915	1916	1917	1918	1919	Plot mean.
A–4–19	(a)	2.7	4.2	11.8	42.0	10.6	25.6	32.3	18.4
A–6–3	0.7	.8	.5	.7	7.4	15.1	9.2	19.5	6.7
B–5–3	.9	3.8	17.6	49.7	96.2	43.7	30.3	95.5	42.2
B–5–4	.2	.8	2.5	10.5	60.5	36.8	42.0	74.3	16.0
Annual mean	.6	2.0	6.2	18.2	51.5	26.5	26.8	55.4	.....

[a] Not planted to cotton in 1912.

This tabular statement shows that these continuously cropped cotton plots have all suffered severely from rootrot. As has been the case with all the plots in the rotations, the disease has become increasingly serious during the later years. The two plots that have had identical treatment, A–6–3 and B–5–3, show wide differences in extent of infection, but this may be due in part to situation, as they are in different parts of the field. The plots B–5–3 and B–5–4 lie side by side. Their tillage treatment has differed only in that B–5–4 has received annual applications of manure. It is not clear that this difference in treatment is responsible for the difference in results, but it may be a contributing factor. It is clear, however, that in A–4–19 the annual use of a green manure crop of field peas plowed under has not been strikingly effective in controlling the disease.

THE TWO-YEAR ROTATIONS

The second category of rotations includes those in which cotton recurs on the same land each alternate year. The extent of rootrot injury in these 20 two-year rotations is shown in Table III.

The outstanding feature of Table III is the wide variation in the extent of rootrot injury in these different rotations, a range in means from 0.8 per cent to 31.9 per cent. If there were reason for believing that these differences in rootrot injury were associated with differences in tillage methods or with different crop sequences, it would appear that the remedy for the disease was to be sought through the adoption of the tillage and rotation methods which have shown the least injury through the period of years. But, unfortunately, a critical study of the facts does not warrant such a conclusion. It is only by detailed analysis of the facts involved that the real significance of the results can be understood. For such a detailed study it may be expedient to separate these 20 rotations into groups with respect to some significant feature of the tillage or rotation practice, as follows.

1. LONG PERIOD OF FALLOW.—Rotation A–4a, cotton grown on land in alternate years, the land being plowed immediately after the crop is picked and kept in clean fallow for about 16 months until the next cotton crop is planted. The history of this rotation shows that very little rootrot developed prior to 1915 but that the injury has been severe during 1918 and 1919. This rotation may be compared directly with A–6–3 and B–5–3, which differ from it only in the length of fallow period, this being 16 months in the first case and 4 months in the other two cases. The mean rootrot injury was 10.5 per cent for the long fallow period and 6.7 and 42.2 per cent for the two short fallow periods. Obviously, the longer fallow period has not shown a definite improvement of condition.

2. CORN, SORGHUM, AND OATS AS INTERVENING CROPS.—Of the 19 two-year rotations which include another field crop, 10 include corn, 6 include sorghum, and 3 include oats. If we disregard all other features of tillage and rotation practice, we find that the 10 rotations, including

corn, show a mean annual rootrot injury of 10.5 per cent, with a range from 1.1 to 31.9 per cent; those including sorghum, a mean of 6.5 per cent, with a range from 0.8 to 19.3 per cent; those including oats show a mean of 10.4 per cent with a range from 2.8 to 16.7 per cent. It is clear from these figures that these different crops do not effect differently the rootrot injury on succeeding crops of cotton.

TABLE III.—*Percentage of plants killed by rootrot in the various two-year rotations at the San Antonio Experiment Farm, 1912 to 1919*

Rotation and plot No.	1912	1913	1914	1915	1916	1917	1918	1919	Rotation mean.
A–4a A4–1	.....	0.1	.....	1.3	.....	4.7	.....	48.6	10.5
A4–2	0	.....	0	.....	3.2	.....	26.5	.....	
A–4d A4–7	.....	1.5	.....	14.0	.....	29.1	.....	27.5	13.0
A4–8	0	.....	0	.....	12.5	.....	19.3	.....	
A–5c1 A5–7	0.3	.....	.2	.....	13.0	.....	9.8	.....	11.7
A5–8	.....	2.1	.....	11.6	.....	17.3	.....	39.0	
A–5c2 A5–9	0	.....	.1	.....	18.0	.....	30.0	.....	10.4
A5–10	.....	.3	.....	4.3	.....	5.6	.....	24.8	
A–5d1 A5–11	.2	.....	.2	.....	22.6	.....	21.2	.....	16.7
A5–12	.....	1.1	.....	14.3	.....	15.0	.....	59.0	
A–5d2, A5–13	.2	.....	0	.....	43.2	.....	46.9	.....	19.3
A–5, A5–14	.....	1.2	.....	6.7	.....	20.8	.....	35.4	
A–5e1 A5–15	.3	.....	1.4	.....	14.8	.....	4.0	.....	2.8
A5–16	.....	.1	.....	0	.....	.2	.....	1.5	
A–5e2 A5–17	0	.....	0	.....	3.7	.....	3.4	.....	1.2
A5–18	.....	0	.....	.2	.....	1.6	.....	.9	
B–5a 9	.....	0	.....	0	.....	0	.....	3.3	.8
10	0	.....	.1	.....	2.2	.....	.4	.....	
B–5b 11	.....	0	.....	.2	.....	0	.....	8.6	3.2
12	0	.....	.1	.....	5.6	.....	11.0	.....	
B–5e 17	.....	2.2	.....	1.3	.....	4.1	.....	15.1	4.3
18	.6	.....	.3	.....	3.0	.....	8.1	.....	
B–6a 1	.7	.....	0	.....	2.0	.....	4.9	.....	1.1
2	.....	0	.....	0	.....	.8	.....	.2	
B–6b 3	0	.....	0	.....	1.3	.....	8.0	.....	2.1
4	.....	.1	.....	0	.....	.8	.....	6.8	
B–6c 5	0	.....	.4	.....	.3	.....	1.7	.....	1.1
6	.....	.6	.....	0	.....	1.9	.....	3.9	
B–6d 7	0	.....	0	.....	.0	.....	8.3	.....	1.9
8	.....	0	.....	.2	.....	1.0	.....	5.4	
B–6e 9	0	.....	.5	.....	4.5	.....	13.8	.....	4.7
10	.....	.2	.....	2.3	.....	3.9	.....	12.6	
B–6f 11	1.1	.....	3.5	.....	51.8	.....	6.5	.....	12.4
12	.....	.7	.....	3.9	.....	10.5	.....	21.3	
B–6g 13	2.5	.....	12.8	.....	98.2	.....	8.5	.....	31.9
14	.....	13.2	.....	45.7	.....	23.2	.....	51.3	
B–6h 15	2.0	.....	4.8	.....	81.7	.....	5.5	.....	26.3
16	.....	1.6	.....	14.2	.....	36.6	.....	63.6	
B–6i 17	.3	.....	.6	.....	15.5	.....	31.4	.....	11.2
18	.....	.6	.....	.4	.....	.3	.....	40.7	

3. EFFECT OF SUBSOILING.—Among the 20 two-year rotations there are five pairs of which the members of each pair differ from each other only in that in one case the land is plowed to the ordinary depth of about 8 inches, while in the other case the plow is followed once during the rotation with a subsoil plow which breaks the ground in the furrow

bottom to the depth of 4 to 6 inches additional. In the five rotations that are not subsoiled the mean of the mean annual rootrot injury is 14.2 per cent, ranging from 1.1 to 31.9 per cent. In the five subsoiled rotations the mean of the means is 7.4, and the range is from 1.2 to 26.3 per cent. Direct comparisons between the members of each pair shows that in only three of the five cases does subsoiling show a reduction of injury, and in only two cases is this difference sufficiently great to be significant.

4. EFFECT OF BARNYARD MANURE.—Direct comparison as to the effect of barnyard manure is possible in two pairs of the two-year rotations, in one pair of the annual or continuously cropped plots, and in one pair of the three-year rotations discussed below, making four in all. In those four cases the mean of the mean annual injury on the unmanured plots is 13.7 per cent, ranging from 1.1 to 42.2 per cent, while for the manured plots the mean is 9.4 per cent and the range from 1.1 to 19.3 per cent. Direct comparisons between the members of each pair shows that in two cases they have the same annual means, while in one case the manured rotation has the higher mean and in the other case the lower mean. From this it must be concluded that the use of farmyard manure has not materially reduced the injury from rootrot.

5. EFFECT OF GREEN MANURE CROPS.—The effect of a green manure crop, either cowpeas or field peas, may be compared in four pairs of rotations of which two are in the two-year group, one in the continuous-cropping group, and one in the three-year group. The mean of the annual means of the four rotations which do not have green manure crops is 14 per cent of rootrot injury, ranging from 1.1 to 42.2 per cent, while the mean for the four in which green manure is used is 10.8 per cent, with the range from 1.9 to 18.5 per cent. These differences are clearly not significant, and the conclusion must be that a green manure crop is not an effective remedy for cotton rootrot.

In addition to the foregoing simple and direct comparisons between several groups of rotation pairs, it is possible to compare the effect of combinations of different treatments against the control rotations. For example, rotation B–6a is a simple corn-cotton rotation, the land being plowed immediately after each crop and kept fallow and in good tilth until the next crop is planted. Rotation B–6b is the same, except that the land is subsoiled after the corn crop. In rotation B–6c the land is manured after the corn crop. In rotation B–6d the land is manured after the corn crop and planted to field peas, which are plowed under preceding the corn crop. In rotation B–6e the land is manured, planted to field peas, and plowed and subsoiled during the period between the corn and cotton crops. These five rotations show progressive combinations of treatments that are often recommended for controlling cotton rootrot. Reference to Table III shows that the mean annual percentage of rootrot injury was much the same in all these rotations, though slightly higher in the

last-named, in which all of the presumably beneficial treatments were combined.

One other feature of these two-year rotations remains to be considered. It is a group in which the land is spring plowed or disked immediately preceding the cotton crop. The four rotations included in this group lie in the south half of series B–6 and have all shown serious injury from rootrot. In the first of these the land is plowed only once in two years, and that immediately following the cotton crop. After the corn crop the land is disked and kept fallow by shallow tillage until the cotton crop is planted. The mean annual rootrot injury has been 12.4 per cent. In the next two rotations the land, though plowed twice in two years, is left undisturbed after the corn crop until just before planting time, when it is plowed, and one of the rotations is also subsoiled at the time of plowing. The rootrot injury on these rotations has been 26.3 per cent for the subsoiled rotation and 31.9 per cent for the one that is not subsoiled. In the fourth rotation in this group the land is disked after the corn crop and sown to rye for green manure which is plowed under in the spring just before the cotton is planted. The annual rootrot injury in this rotation is 11.2 per cent. While it seems inadvisable to make direct comparisons between these rotations and other cotton-corn rotations such as B–6a, because of the difference in field location, it is clear that none of these treatments has checked rootrot injury.

As a summary of these results from the two-year rotations, it may be said that the extent of rootrot injury appears not to have been influenced either by different crop sequences or by different tillage methods or by the use of barnyard manure or green manure crops.

THREE-YEAR AND FOUR-YEAR ROTATIONS

On the black lands of Texas where cotton is the leading field crop it is hardly practicable to consider the use of a rotation which does not involve cotton as frequently as every third year, or at most, every fourth year. If a period of two years or three years without cotton is not sufficient to secure a rotation effect, then it is clear that rotation effect must be dispensed with. As indicated above, the San Antonio rotation experiment includes four three-year rotations and two four-year rotations. The detailed record of rootrot injury in these six rotations is shown in Table IV. Two of the three-year rotations and both of the four-year rotations were started in 1913.

While four of the six rotations included in Table IV show very slight rootrot injury, the other two—that is, one three-year and one four-year—show an extent of injury comparable with the plots cropped to cotton continuously. In other words, these results do not justify the hope that a relatively long period without cotton leaves the land less likely to show rootrot injury when cotton is again planted. It is true that these longer rotations differ from each other in certain respects, but these differences

are of the same sort that in the shorter rotations were found to be without effect on the extent of rootrot injury. Thus, rotation B–4a, which shows a mean annual loss of only 0.6 per cent, differs from rotation B–4b with a annual loss of 6.9 per cent only in having a year of Sudan grass instead of oats followed by field peas. Likewise, in the four-year rotation one of these, A–4f, with an annual loss of 0.4 per cent, differs from the other, having an annual loss of 15.0 per cent, only in that the field peas are cut for hay instead of being plowed under. These differences of treatment can hardly be regarded as sufficient to account for the striking differences in the extent of rootrot injury.

Having in view the whole of the results from these rotation experiments, one is forced to the conclusion that the control of rootrot is not to be found through any ordinary system of crop rotation or of tillage methods.

TABLE IV.—*Percentage of plants killed by rootrot in the various three-year and four-year rotations at the San Antonio Experiment Farm, 1912–1919*

THREE-YEAR ROTATION

Rotation and plot No.	1912	1913	1914	1915	1916	1917	1918	1919	Rotation mean.
A–5a 1	.....	0	.....	.....	2.0	.....	.....	4.7	1.3
A–5a 2	0	.....	.....	0	.....	.....	0	.....	
A–5a 3	.....	.....	2.0	.....	.....	1.8	.....	.....	
A–5b 4	.....	0	.....	.....	0	.....	.....	4.2	1.2
A–5b 5	0	.....	.....	0	.....	.....	2.5	.....	
A–5b 6	.....	.....	(a)	.....	.....	1.6	.....	.....	
B–4a 14	.....	.....	(a)	.....	.....	0	.....	.....	.6
B–4a 15	.....	0	.....	.....	0	.....	.....	1.8	
B–4a 16	.....	.....	.....	.9	.....	.....	.7	.....	
B–4b 17	.....	.....	(a)	.....	.....	2.6	.....	.....	6.9
B–4b 18	.....	.2	.....	.....	9.3	.....	.....	26.5	
B–4b 19	.....	.....	.....	1.4	.....	.....	1.5	.....	

FOUR-YEAR ROTATION

A–4f 11	.....	.....	.....	.....	1.7	.....	.....	.....	.4
A–4f 12	.....	.....	.....	0	.....	.....	.....	.7	
A–4f 13	.....	.....	0	.....	.....	.....	.1	.....	
A–4f 14	.....	.4	.....	.....	.....	.1	.....	.....	
A–4g 15	.....	.....	.....	.....	25.6	.....	.....	.....	15.0
A–4g 16	.....	.....	.....	18.5	.....	.....	.....	51.9	
A–4g 17	.....	.....	1.5	.....	.....	.....	.5	.....	
A–4g 18	.....	3.8	.....	.....	.....	2.9	.....	.....	

[a] No record.

LIFE HISTORY OF RECURVARIA MILLERI, THE LODGEPOLE PINE NEEDLE-MINER, IN THE YOSEMITE NATIONAL PARK, CALIFORNIA

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INTRODUCTION

The lodgepole pine needle-miner (*Recurvaria milleri* Busck) infests the needles of the host tree, *Pinus murrayana* Oreg. Com., causing them to fade and later fall from the trees. The result is defoliation in the infested areas. Stands of timber affected by the needle-miner can not be distinguished superficially by the untrained woodsman from those infested by bark-beetles of the genus Dendroctonus. To prevent needless waste of timber and money, therefore, it is very desirable that control operations against barkbeetles, namely, the felling of the trees, should not be undertaken where only the less serious, and usually not fatal, needle-miner infestation occurs.

The only serious epidemics of the needle-miner which have been recorded occur in the lodgepole pine stands of the Yosemite National Park of California. The studies presented in this paper were made in these epidemic areas during the summer seasons of 1917, 1918, and 1919. The investigations were confined exclusively to the Yosemite National Park, and the studies presented apply specifically to the insect in this locality only.

HISTORICAL REVIEW

In 1903 it was reported to the Bureau of Entomology through the Secretary of the Interior that large areas of lodgepole pine in the Yosemite Park were affected by a leaf-mining moth. In May, 1904, Dr. A. D. Hopkins visited the Yosemite Park, planning to investigate the conditions which had been reported, but was unable to reach the lodgepole pine areas, as all trails leading into the region were still closed by heavy snows. In 1906 Mr. H. E. Burke spent the month of July in the Tenaya Basin and Tuolumne Meadows, but found no evidence of the needle-miner in that vicinity, although a considerable amount of timber was being killed by the mountain-pine beetle (*Dendroctonus monticolae* Hopkins). Later, in 1907, Prof. J. H. Comstock reported its presence in the park to Dr. L. O. Howard, stating that he saw large areas of tamarack pine (as lodgepole pine is called locally) infested by the moths.

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Key No. K-94

During the summer of 1911 Forest Pathologist Dr. E. P. Meinecke made a reconnaissance through the Tenaya Basin and Tuolumne Meadows and reported widespread infestation by a needle-miner and a heavy flight of moths which occurred in July and August of that year.

In October, 1912, Mr. J. M. Miller made a trip into the Tenaya Basin and on into the Tuolumne Meadows and found that the barkbeetle infestation reported by Mr. Burke had spread and was threatening the lodgepole pine stands in both the Tenaya and Cathedral Basins. At the same time the infestation of the lodgepole pine needle-miner was conspicuous in both watersheds. At that time the insect was in the larval stage in the needles of the host, having mined such a high percentage of them that the foliage cast of the entire forest presented a dull brownish color. The general effect was suggestive of the scorching resulting from fire. Subsequent examinations by Mr. Miller in 1913 and 1914 indicated that the infestation of the insect was distributed throughout about 30,000 acres in the National Park, extending through the main Tuolumne Watershed and the upper basin of Tenaya Creek, a tributary of the Merced. It was limited, however, to lodgepole pine growing between the elevations of 7,000 and 9,000 feet. Where the infestation had been prevalent for several years, the stands were usually defoliated to a considerable degree. Adult specimens collected by Mr. Miller in 1913 were later described as a new species, *Recurvaria milleri*, by Mr. August Busck.[1]

The writer was assigned in 1917 to a special study of the insect by his immediate superior, Mr. Miller.[2] The program of the work as outlined at that time consisted of field studies and experiments to be conducted throughout the period of activity of the insect in the infested areas during the spring and summer of 1917, 1918, and 1919. This original outline was not changed, and the investigations were carried out in connection with the studies of a barkbeetle which infests the host tree in the same locality.

During the early summer of 1918 Mr. Carl Heinrich, specialist in forest Lepidoptera of the Bureau of Entomology, accompanied the writer on a field trip into the infested areas.[3]

CONDITION OF INFESTED STANDS

Where the needle-miner has been prevalent, the first noticeable result, aside from the brownish cast of the foliage caused by the color of the affected needles, is a distinct phase of defoliation. This is caused by the falling of a very high percentage of the needles which have been attacked. After several years of repeated defoliations a noticeable dying of the crowns and ends of branches, a stunting of growth, and a general decadent

[1] BUSCK, August. DESCRIPTIONS OF NEW MICROLEPIDOPTERA OF FOREST TREES. *In* Proc. Ent. Soc. Wash., v. 16, no. 4, p. 143–150, pl. 7–8. 1914.

[2] Studies and records made by Mr. Miller in 1913 and 1914 have been freely used by the writer as a basis for his investigations, and acknowledgment is made of the value of these first records.

[3] Suggestions made by Mr. Carl Heinrich at the time of this trip and subsequent assistance in the determination of material sent to him have been of great help to the writer.

appearance of the trees becomes apparent (Pl. 30). It has been noted that this latter damage is most severe and conspicuous in mature or overmature stands, such as are found in the Tenaya and Cathedral Basins. There is a striking contrast in the degree of damage in different localities of the infested area. In the northern part of the Tuolumne Basin, in the vicinity of Kerrick Canyon, the damage is much less severe than in the Tenaya and Cathedral Basins, although the infestation has been present fully as long in the northern locality as in the southern. Dying tops and limbs would, of course, result from pathological conditions produced by other causes than the needle-miner. No disturbances aside from the needle-miner have been noted; but the pathological aspects of the problem have not been thoroughly studied.

It has also been noted that the degree of damage varies greatly according to the site of the host tree. Trees standing on rocky, exposed sites, under unfavorable soil and moisture conditions, suffer much more severely than those standing on meadows where there is abundant soil and moisture.

Much of the timber defoliated by the needle-miner has been attacked and killed by an entirely different insect, the mountain-pine beetle (*Dendroctonus monticolae*). No direct biological association, however, exists between the needle-miner and the barkbeetle, although the badly defoliated trees are apparently so weakened that they offer little, if any, resistance to the attacks of the beetles.

Final and complete killing of the trees as a result of the needle-miner damage alone has not been recorded, although some of the more severely affected have reached a condition that offers little hope for their ultimate recovery. The insidious character of the needle-miner damage is not readily apparent in areas of recent invasion, but is very noticeable in stands where the infestation has persisted for a number of years. This will be readily understood by reference to the diagrams (fig. 1–3), which show that the attacks upon the needles occur in such manner as to allow the trees a breathing spell sufficient to maintain their vitality for a few years after the initial attacks.

LIFE CYCLE

The length of the life cycle is 25 months and covers a period of 1 year and parts of 2 other years. The individual broods hibernate during two winter periods of approximately 6 months each. The feeding periods of the larvæ occur during parts of 3 years, aggregating a total period of 11 months. Flight occurs every alternate year, as in 1913, 1915, 1917, and 1919. During the alternate years from flight the broods are found in the larval stage in the needles of the current or previous year's growth.

Emergence and flight of the adults occur during the period from July 1 to August 31. For illustration of life cycle see figure 1. Some few individuals may be seen earlier or later than these dates, but they represent only advanced individuals and stragglers. During the period of

maximum flight thousands of adults may be seen on the wing and crawling over the foliage of the host and other trees. Many of them fall into the streams and on the numerous small lakes and perish; thousands may be seen floating on the surface of the water. During this period the flying moths become a pest to campers in the locality, as they invade the tents and fall into the cooking utensils and provisions.

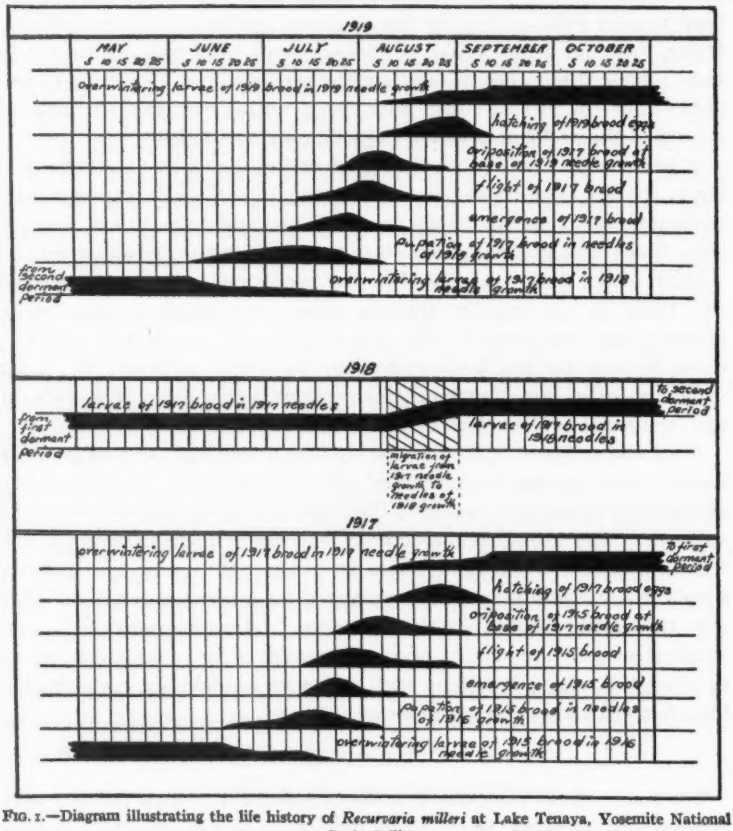

1919
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
overwintering larvae of 1919 brood in 1919 needle growth
hatching of 1919 brood eggs
oviposition of 1917 brood at base of 1919 needle growth
flight of 1917 brood
emergence of 1917 brood
pupation of 1917 brood in needles of 1919 growth
from second dormant period
overwintering larvae of 1917 brood in 1918 needle growth
1918
larvae of 1917 brood in 1917 needles
from first dormant period
larvae of 1917 brood in 1918 needles
To second dormant period
migration of larvae from 1917 needle growth to needles of 1918 growth
1917
overwintering larvae of 1917 brood in 1917 needle growth
To first dormant period
hatching of 1917 brood eggs
oviposition of 1915 brood at base of 1917 needle growth
flight of 1915 brood
emergence of 1915 brood
pupation of 1915 brood in needles of 1916 growth
overwintering larvae of 1915 brood in 1916 needle growth

FIG. 1.—Diagram illustrating the life history of *Recurvaria milleri* at Lake Tenaya, Yosemite National Park, Calif.

The eggs are deposited on and under the needle sheaths at the base of the needles. Occasionally eggs are found on the terminal shoots near the base of the needles. Larvæ begin to hatch about August 5 and continue hatching until about September 10. Attack by the young larvæ on the tender needles of the current year's growth begins soon after hatching. The young larvæ invariably attack the new needles by boring in near the outer ends, and they always work toward the petiole, never in the opposite direction. This peculiarity of habit permits of a

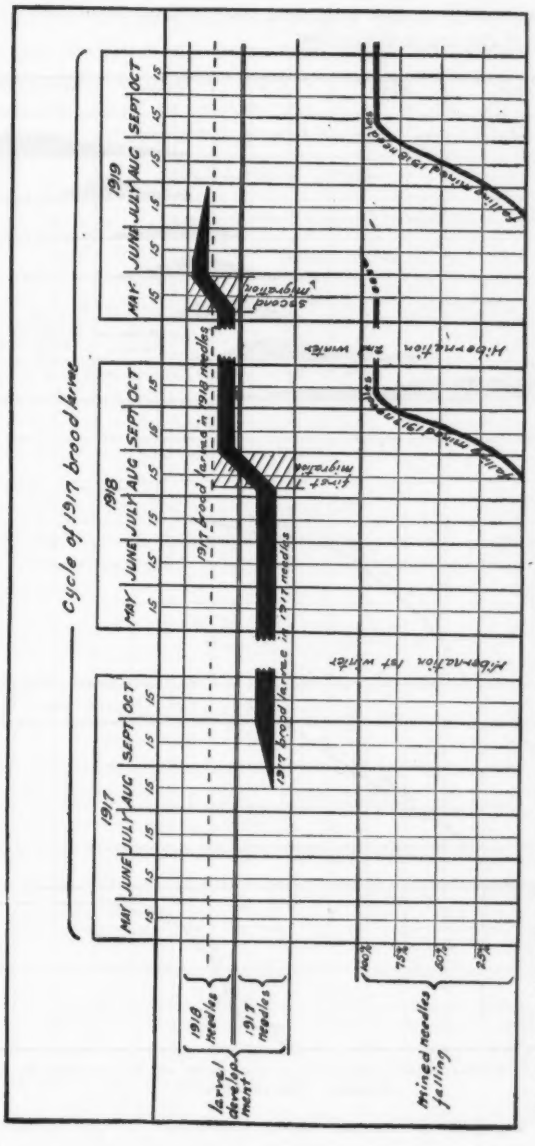


FIG. 2.—Diagram illustrating life cycle of *Recurvaria milleri* larvæ and the periods of larval migrations, as well as the periods of falling of the mined and abandoned needles.

longer life for the attacked needles and insures fresh material for the larvæ to feed upon. By the latter part of October the larvæ have grown to be approximately 2 mm. long and have mined about one-third the outer length of the infested needles.

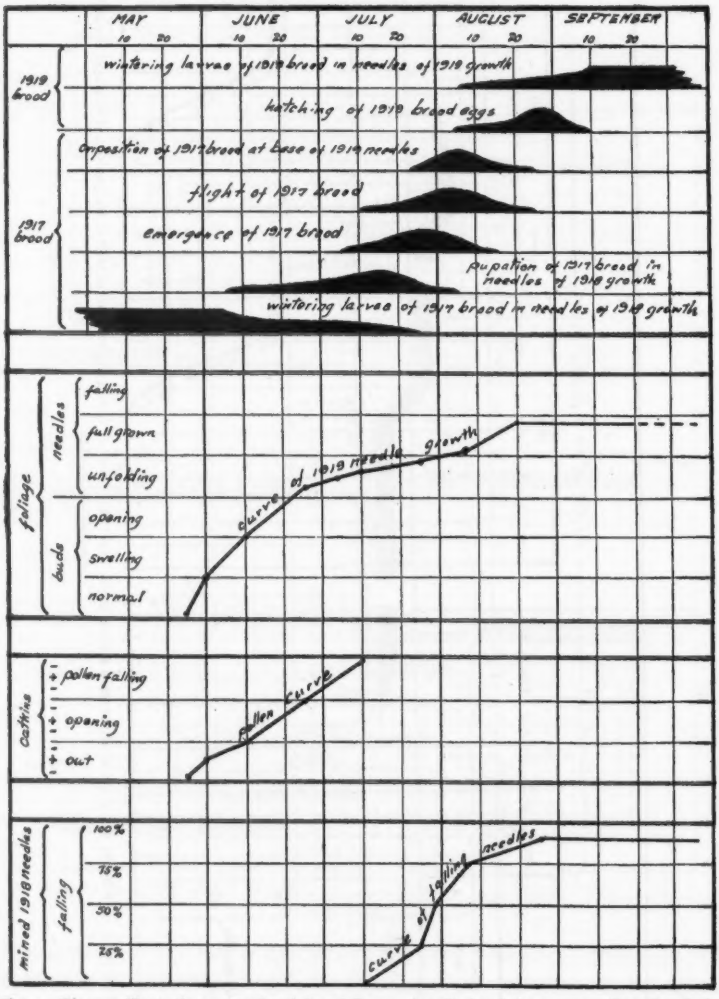


FIG. 3.—Diagram illustrating seasonal activity of *Recurvaria milleri* and the corresponding phenological phenomena of the host plant.

Owing to the high elevations, above 7,000 feet, of the infested areas, winter conditions set in during the latter part of October and insect activity ceases until the following spring. During the winter of the first season the insect hibernates as immature larvæ in the partially mined needles.

Activity is resumed in early May of the next spring, and the brood develops as larvæ throughout the growing period of the second season. By the middle of July the larvæ have mined two-thirds the length of the infested needles attacked during late summer of the previous year and are about half-grown, or nearly 4 mm. long.

Beginning about August 5 of this season, or when the new needles of this year's growth are nearly full-grown, the larvæ begin to leave the mined needles in which the previous winter was passed and migrate to these new needles. The migration covers the period from August 5 to September 1, when practically all the brood is in the new needles (fig. 2, 3). During this period the migrating larvæ are exposed and may be seen crawling about on the needles and twigs. Undoubtedly a high mortality occurs during the migration, but no statistics are available to show this. By the first of September the larvæ are well established in the new needles of the current year's growth which are attacked near the outer ends. These new and tender needles are mined very rapidly so that by September 15 one-half the length of each infested needle has been eaten.

Toward the latter part of October and the arrival of winter conditions the brood again ceases feeding and becomes dormant, passing the second winter as nearly mature larvæ in the first-attacked needles of the second season's growth.

Activity is again resumed the following spring in early May. During this spring-feeding period the larvæ complete the mining of the needles in which the brood hibernated. These mined needles are then abandoned and the larvæ attack green needles of the same growth, which by the last of May are from one-half to three-fourths mined; the larvæ, now being full-grown, cease feeding and prepare the larval tunnels for pupation in the needles mined last. These tunnels are slightly lined with silk and have emergence tubes leading to the covered exit holes near the tips of the needles. By the close of the second spring-feeding period each larva has mined an approximate average of two needles of the preceding year's growth. Thus, each larva mines three needles during its life cycle of 23 months—one during the first season of attack and one after each of the two migrations (fig. 2). From this it is obvious that of the crop of needles which develops after the season of initial attack twice as many needles are mined as of the crop which receives the initial attack. This accounts for the more conspicuous color phase and defoliation which are apparent every alternate year (Pl. 29, D).

Pupation begins about June 10 and is continued until August 5. Pupæ form in the mined needles with the heads toward the tips. Emergence of the adults begins about July 1. Soon after the mined needles are abandoned by the migrating larvæ or the emerging adults, the needles begin to fall from the trees (fig. 2, 3).

THE MOTH

DESCRIPTION

The adult is a small, grayish moth with a wing expanse of 12 to 15 mm. The head, fore wings, and thorax are of a silvery gray color irregularly marked with black. The antennæ are white annulated with black. The face is white. The hind wings are white dusted with fuscous; the cilia slightly ocherous. The abdomen is silvery white. The legs are white barred with black. The females are slightly larger than the males. (Pl. 29, A.)

EMERGENCE, LONGEVITY, AND HABITS OF FLIGHT

The moths emerge every alternate year, as in 1913, 1915, 1917, and 1919. First adults appear in the field between July 5 and 10, and emergence is continued until about August 15, reaching a maximum about July 25. The average length of life of the adults, as appears from data obtained on adults reared in field cages, is approximately 14 days. All observations indicate that the moths are most active during the warmer part of the day; myriads may be seen flying during the maximum period of flight and active on the foliage of the host on warm days between 10 a. m. and 4 p. m. After 4 p. m. at these high altitudes the temperature drops considerably and the moths cease flying and are not so active on the foliage. On cloudy days the moths hide away among the foliage and in the crevices of the bark of the tree trunks and fly out only when disturbed.

MATING AND EGG LAYING

Copulation was observed in the field on one occasion only. Numerous observations were made in the field and on moths kept captive in a cage to determine the approximate period of mating, but this one instance is all that was recorded. This occurred about 11 a. m., July 25, 1919. When first noted the pair was attached and quietly resting on a small lodgepole pine branch a few inches from its outer end.

Oviposition was observed once only and in the field at 1 p. m., July 27, 1919. When first noted, the moth was in position to oviposit at the base of the 1919 needle growth on the tip of a small twig about 5 feet above the ground. It was facing the tips of the young needles and had the ovipositor inserted between and under the needle sheaths and against the branchlet. This appears to be the normal position, as practically all the eggs that were found in the field were located under the needle sheaths or on the surface of the twigs near the base of the 1919 needle growth. (Pl. 29, B.) After this moth had been under observation for five minutes she was collected and it was found that she had deposited three eggs in this position. Later the moth was dissected and nine more eggs were secured. The foregoing record of oviposition was made

during the period of maximum flight of the adults. On numerous other occasions moths were observed running actively over the foliage, occasionally stopping and pressing the tip of the abdomen against the base of the needles as though attempting to oviposit. Freshly laid eggs were found in the field during the latter part of July and throughout August, 1919. (Table I.)

TABLE I.—*Period of egg laying of Recurvaria milleri*

Date of observation.	Number of eggs in record.
1919.	
July 24.....	3, at base of needles.
27.....	7, at base of needles.
30.....	8, at base of needles.
Aug. 4.....	10, at base of needles.
8.....	5, at base of needles.
20.....	8, at base of needles.
25.....	3, at base of needles.

It was not determined whether one individual female deposits eggs in more than one place or not; neither was the total number of eggs deposited by individual females ascertained. Clutches of eggs found in the field averaged from five to six in number. (Tables I and II.)

TABLE II.—*Number of eggs of Recurvaria milleri found in clutches in the field*

Clutch No.	Number of eggs.
1	3
2	7
3	8
4	1
5	10
6	3
7	5
8	8
9	1
10	3
Total.....	49

THE EGG

DESCRIPTION

The normally deposited egg is oblong oval, rugose, and translucent, with iridescent surface reflections. The average size is 0.3 by 0.5 mm.

WHERE DEPOSITED

The eggs are usually deposited at the base of the current year's growth of needles and are concealed under the needle scales. Occasionally they

are found on the surface of the terminal twigs, but always close to the late needle growth. Wherever found they are not securely attached. (Pl. 29, B.)

PERIOD OF INCUBATION

Incubation lasts approximately from 12 to 14 days. The maximum time required for the eggs to develop, as recorded in the season of 1919, was 14 days, the minimum 12 days, and the average 13 days. Records on the incubation of eggs for the season of 1919 are given in Table III.

TABLE III.—*Incubation period of eggs of Recurvaria milleri, season of 1919*

Number of eggs in record.	Date of deposition.	Date of hatching.	Incubation period.
			Days.
5	July 27	Aug. 8	12
3	27	9	13
1	30	13	13
4	30	14	14

THE LARVA

DESCRIPTION

The mature larva is roughly cylindrical; its average length is 8 mm., or from seven to nine times the width. The color varies from light lemon yellow to deep orange, with an indistinct darker red patch along the dorsal median line. The head is black with dark brown thoracic shield, and the anal plate is lighter brown. The prolegs are on the sixth, seventh, eighth, and ninth abdominal segments.

HABITS OF LARVÆ

The larvæ feed on the interior of the needles by boring in near the outer ends and working toward the bases, constructing longitudinal mines which vary in length from one-third to the entire length of the needles (Pl. 29, C). The frass and excrement are ejected through the entrance hole as fast as accumulated. The larvæ are very active; when disturbed they retreat through the needle mines, backing out through the entrance holes, and occasionally letting themselves down by means of a thread spun from the silk glands.

The first stages of the larvæ are passed in the young needles of the current year's growth. The first winter is also passed in these needles. When the needles of the next crop arrive the following summer the larvæ migrate to them and feed until the dormant period of the second winter begins; the second hibernation occurs in these needles. When activity is resumed the second spring the larvæ complete the mining of the needles in which the winter was passed and enter fresh needles of the

same growth. When these are partially or completely mined the now mature larvæ prepare pupal cells in the last-mined needles and envelop themselves in thin silk. During its life each larva mines an average of three needles. (Fig. 1.)

LENGTH OF LARVAL STAGE

The maximum length of the larval stage is 23 months, or from August 15 of the first year to July 1 of the third year (Table IV).

TABLE IV.—*Duration of the larval stage of Recurvaria milleri*

Date of observation.	Development and activity of larvæ.
Aug. 15, 1917, to June 1, 1918.	No observations were recorded for this period.[a]
June 4, 1918	Larvæ 3 mm. long; feeding in needles of 1917 growth.
June 13, 1918	Larvæ 3.5 mm. long; feeding in needles of 1917 growth.
June 22, 1918	Do.
July 13, 1918	Larvæ 4 mm. long; feeding in needles of 1917 growth.
July 20, 1918	Larvæ 5 mm. long; feeding in needles of 1917 growth.
Aug. 5, 1918	Larvæ in mined needles of 1917 growth and entering unmined needles of 1918 growth.
Aug. 12, 1918	Larvæ in mined needles of 1917 growth and entering unmined needles of 1918 growth; many larvæ in migration exposed on foliage.
Aug. 23, 1918	Larvæ in mined needles of 1917 growth and entering unmined needles of 1918 growth; only a few individuals remaining in mined needles of 1917 growth.
Sept. 4, 1918	Larvæ 5.5 mm. long; all in needles of 1918 growth.
Sept. 15, 1918	Do.
Sept. 16, 1918, to May 24, 1919.	No observations were recorded for this period.[a]
May 24, 1919	Larvæ 6 to 7 mm. long; in mined needles of 1918 growth.
	Larvæ migrating from mined 1918 needles to unmined needles of same growth.
June 1, 1919	Do.
June 10, 1919	Larvæ 7 to 8 mm. long; in freshly mined needles of 1918 growth.
June 25, 1919	Prepupal larvæ and pupæ in mined needles of 1918 growth.
July 10, 1919	Do.
July 25, 1919	Do.

[a] The absence of records for these periods is due to the author's absence from the park.

THE PUPA

DESCRIPTION

The pupæ are dark brown to black in color and are approximately 1.2 mm. in diameter by 6 mm. long. They are found in thin silk cocoons in the last needles mined by the larvæ. (Pl. 29, C.)

LENGTH OF PUPAL STAGE

The maximum pupal stage lasts from June 20 to July 20, or 30 days.

HOST PLANT

These studies were confined exclusively to the Yosemite National Park, Calif., wherein the insect was found attacking only one host tree, the lodgepole pine (*Pinus murrayana*).

NATURAL ENEMIES

In connection with the work on this species, the following 10 species of hymenopterous parasites have been reared from prepupal larvæ:

Apanteles n. sp.	Det. C. N. Muesebeck
Angitia sp.	Det. R. A. Cushman
Aethecerus n. sp.	Det. R. A. Cushman
Scambus sp.	Det. R. A. Cushman
Epiurus sp.	Det. R. A. Cushman
Euteles n. sp.	Det. S. A. Rohwer
Habrocytus n. sp.	Det. S. A. Rohwer
Copidosoma sp.	Det. A. B. Gahan
Elachertus sp.	Det. A. B. Gahan
Eulophid	Det. A. B. Gahan

Of these parasites the Copidosoma and the Euteles are most abundant. In 1919 the writer obtained only the following: *Euteles* n. sp., *Copidosoma* sp., *Epiurus* sp., *Aethecerus* n. sp., *Apanteles* n. sp., *Habrocytus* n. sp., and the eulophid. In this year 234 of the 1,886 host larvæ examined were parasitized; thus the seven species listed above produced in this year a parasitism of approximately 12 per cent.

In addition to the foregoing insect enemies there is a small bird known locally as the "pine siskin" that in a few instances has been observed feeding on the adults during the flight period.

LARVAL MORTALITY

During the studies in the spring of 1919 a number of mature larvæ were collected to determine the relative mortality in this stage. Mortality during this stage only was studied, as it was practically impossible to obtain field data of this character for any other stage. A total of 1,886 larvæ were examined; of this number 178, or 9 per cent, were dead and more or less withered. The cause of this mortality was not determined, though it is probably a bacterial disease.

DISTRIBUTION

The distribution of the lodgepole pine needle-miner in the Yosemite National Park is confined to the lodgepole pine stands in the higher elevations north of the Merced Canyon. The extent of this distribution is shown on the map (fig. 4).

One striking feature of its distribution is its occurrence only in distinct zones or areas of epidemic infestation. Within these areas the infestation is abundant, involving every tree with resultant severe damage to the entire stand. Outside of the infested areas the insect does not occur in the larval stage at all, or in such minor degree that no trace of it can be found. Only along the borders of the infested areas have trees been found which contain only a low percentage of affected needles.

These areas of epidemic infestations occur only in belts between two fairly definite contours of elevation. The larval infestation has not

been found below 7,000 feet elevation and rarely above 9,000 feet, although the lodgepole pine stands extend both above and below these contours.

The reasons for these distinct limits to the distribution of the insect have not been determined. The moths in flight have been recorded in

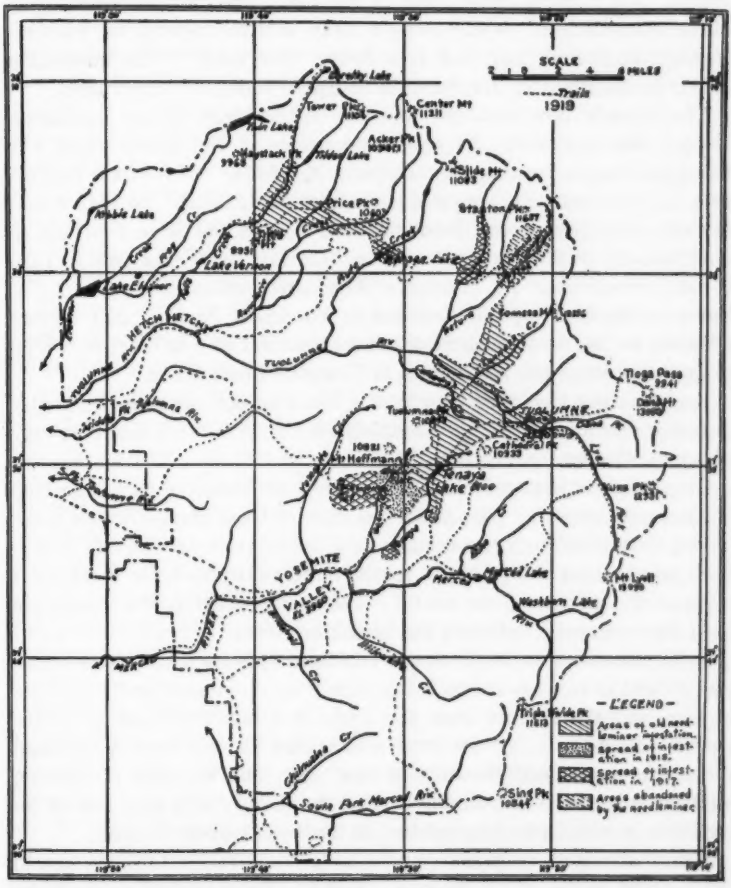


FIG. 4.—Map of the Yosemite National Park, Calif., showing range of distribution and areas infested with *Recurvaria milleri*, 1919.

localities many miles outside of the infested areas; in one instance in the Yosemite Valley at an elevation of 4,000 feet, 6 miles distant from the nearest infestation, and on Cathedral Peak, at an elevation of 10,000 feet, moths were abundant 3 miles distant from the nearest infestation. No trace of larval infestation has ever been found in either locality.

In 1919 the infested areas were determined as follows: South of the Tuolumne River in Tenaya and Cathedral Creek Basins, Snow Flat and Porcupine Flat, and Ten Mile Meadows; on the headwaters of the Tuolumne River throughout the Tuolumne Meadows as far east as Lambert Dome and the terminus of the Lyell Fork Canyon; down the Tuolumne River to and throughout Conness and Alkali Creek Basins and Glen Aulin. The infested areas north of the Tuolumne Canyon occur in the Matterhorn Canyon, around Benson Lake, and throughout the canyons of Kerrick, Stubblefield, and Jack Main. The range of the infestation covers an approximate total area of 60 square miles, or 39,000 acres.

The records now available indicate an advance of the infestation toward the southwest. In 1906 no evidence of the needle-miner was found in Tenaya Basin or the Tuolumne Meadows. In 1911 the infestation was prevalent and conspicuous in both these areas. In 1912 it had not advanced beyond the divide between Tenaya and Snow Flat, but in 1917 infestation was very heavy throughout this latter area, and in 1919 it was conspicuous in Porcupine Flat still farther southwest. The limits of the host type are reached in Porcupine Flat, so that further advance to the west will necessitate a migration of 6 miles over a high ridge to the lodgepole pine stands in Yosemite Creek Basin.

Records show that the invasion of a new area occurs suddenly, the infestation reaching an epidemic condition in one year, with resultant very heavy defoliation from its inception.

Old centers of infestation are indicated in the stands in Jack Main and Matterhorn Canyons. The greater portion of these stands is now dead, having been killed by the mountain-pine beetle years ago, but all indications point to the fact that the needle-miner was present in these areas prior to the advent of the beetle. The needle-miner is still present in both these canyons, infesting the remaining trees.

In Virginia Canyon, north of the Tuolumne Meadows, the needle-miner was present in 1911, as shown by the mined needles found under the trees in 1913 and the absence from the twigs of a heavy percentage of the 1910 needle growth; but for some reason that has not been determined the moths abandoned the area in that year, and no trace of existing infestation has since been found. This is the only area now free of infestation in which previous infestation has been known to exist.

Heavy stands of lodgepole pine occur in the Illilouette Basin and in other areas south of the Merced Canyon. These are the only large stands of lodgepole pine left within the park that have not been invaded by the needle-miner, although they are situated in the same zones of elevation as are the heavily infested areas around Tenaya. Invasion of these stands by the needle-miner may occur at any time; in fact, the infestation is drifting in this direction, as is indicated by a small area of infestation which appeared in 1919 on the slopes of Clouds Rest just across the Merced River from the Illilouette Basin.

POSSIBILITIES OF CONTROL

It is evident that the insects and other natural enemies of the moth have not been sufficient to maintain control on the greater part of the area involved in the epidemic. Artificial measures are at once suggested by the information now available relating to the various stages of the insect's life history.

The use of sprays, which is usually resorted to for the control of infestation of this character, does not appear practicable for application throughout extensive forest areas where every tree is infested, because this method to be successful requires very thorough and frequent applications. Because of the peculiar life history of the species, however, contact sprays would be more valuable than stomach poisons since, during the egg and initial larval stage and before the young larvæ have entered the tips of the needles, both eggs and larvæ are exposed and contact sprays would reach them. Stomach poisons would be effective only when the larvæ are eating their way into the needles.

The infestation could also be attacked by felling the infested trees. During the feeding periods of the larvæ the felling of the trees would cause the death of the needles and the larvæ thus deprived of their food supply would soon succumb. This method, however, would call for the felling of every infested tree in the entire stands involved in the epidemics. For this reason the method is impracticable and can not be considered except in the case of a few trees which might threaten a non-infested stand. Such situations, however, have not been observed in this epidemic.

On the whole, it is doubtful if costs of applying any method of control against the moth would be warranted by the present value of the lodgepole pine stands in the Yosemite National Park. This species has little commercial value, and even for park purposes it is not nearly so desirable as other species.

These silvicultural features should be considered in any scheme of forest protection for the Yosemite National Park. In many sites where the mature lodgepole pine has been killed out by barkbeetle epidemics following in the wake of the needle-miner invasions, mountain hemlock and fir are reproducing to a most encouraging extent. These latter species are more desirable for park purposes in many ways and are not subject to the insect epidemics which are killing the lodgepole pine. It is the opinion of the writer that the great amount of funds which would be required for the protection of the lodgepole pine could be spent to better advantage to encourage the reproduction of more desirable species.

PLATE 29

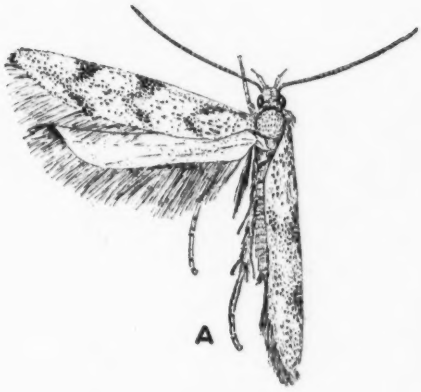
Recurvaria milleri:

A.—Imago. (Drawn by Miss E. Armstrong.)

B.—Twig of lodgepole pine showing the 1919 needle growth: *a*, Eggs and their location between scales at base of needles. The needles which covered the eggs have been removed in order to expose them for photographing. Print slightly retouched. Approximately × 2.

C.—*a*, Lodgepole pine needle showing larval mine; *a1*, entrance hole of larva; *b*, larva exposed in needle mine; *c*, pupa in normal position in needle; *d*, parasitized larva in normal position in needle. Approximately × 2.

D.—Terminal twig of lodgepole pine showing partial defoliation The 1919 needle growth is at tip of twig and shows full complement of needles, as the photograph was made prior to the 1919 attack by the moths. The almost denuded section of the twig immediately below supported the 1918 needle growth, which was mined by the larvæ and has since fallen. The 1917 growth appears just below and shows as nearly a complete set of needles. Still farther down the twig the 1916 growth shows defoliation comparable to the 1918 growth section. Note difference in degree of defoliation every alternate year, the heaviest occurring the year preceding flight. This is accounted for by the fact that the larva mines two needles of this year's growth as compared to one needle of the growth produced in the year of flight, which receives the initial attack by the young larva. The same conditions are shown on the twig branch to the right.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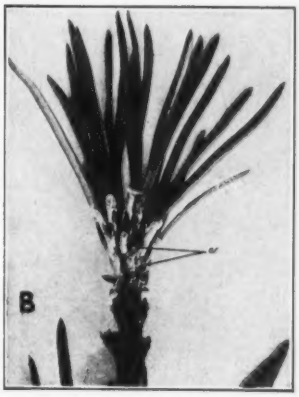
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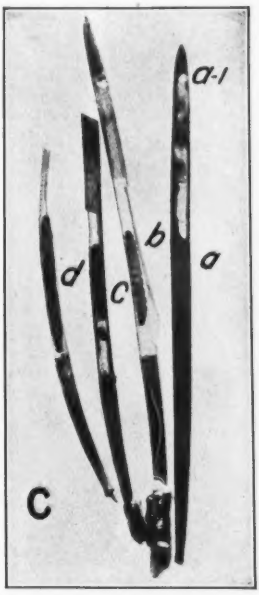
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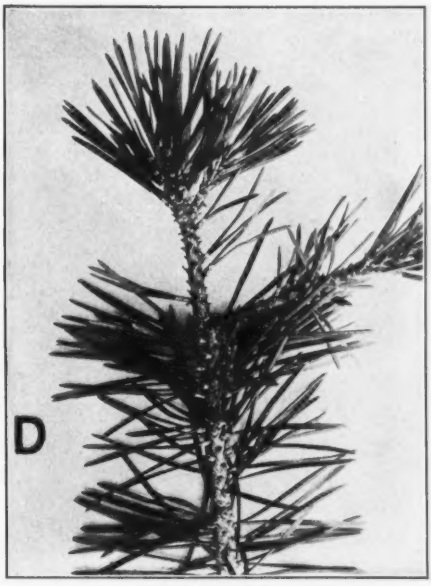
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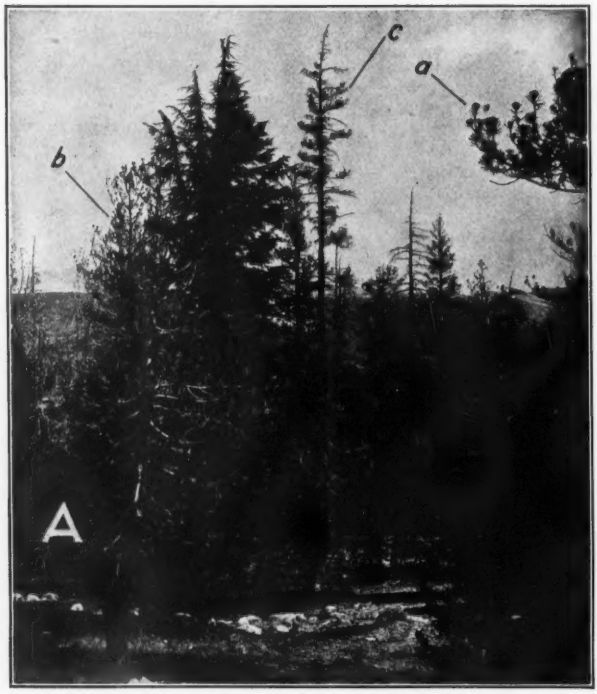
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PLATE 30

Recurvaria milleri:

A.—Lodgepole pine stand showing damage. This stand has suffered for years by repeated defoliations. The defoliated condition of the lodgepole pine is plainly indicated by comparison with the mountain hemlock (the dark-colored tree showing full complement of needles). The three stages of defoliation are well illustrated in this photograph: *a*, First stage, indicated by partially defoliated twigs on limbs in upper right foreground. Only the 1919 growth on the tips of the twigs shows as full a complement of needles. The annual growth prior to 1919 has suffered to a greater or less degree by defoliation. This stage represents the initial stage of damage. *b*, Second or intermediate stage, shown by appearance of tree in left foreground. This tree has suffered severely by defoliation, many twigs being dead and the foliage almost entirely gone. The 1919 needle growth is stunted, indicating weakened vitality. *c*, Third and last stage, indicated by tall tree in center, just to right of hemlocks. Note the dead crown and limbs and almost entire absence of foliage.

B.—Lodgepole pine stand which has suffered severely by defoliation. Every tree has been repeatedly attacked for years. Note the dead crowns and limbs and scarcity of foliage. The top of the small tree in the foreground shows heavy damage to young, vigorous trees, as well as to the mature trees in the background.

A BACTERIAL BUDROT OF CANNAS

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INTRODUCTION

The disease described in this paper was first observed by the writer in July, 1918, when the unsightly appearance of hybrid canna plants (*Canna indica* L.) in the public grounds in Washington (Pl. 31) drew attention to it. The most noticeable lesions at that time were large, irregular brown spots which caused distortions of the leaves. Close inspection showed that many plants were attacked to a greater or less degree; leaves of all ages were involved, and often young shoots were killed by the destruction of the bud. A microscopic examination of sections of diseased areas disclosed the presence of swarms of bacteria in the tissues; and, as no mention of the disease was found in literature, a definite investigation was undertaken.

APPEARANCE OF DISEASED PLANTS

This disease is essentially one of young tissues and moist conditions. This is evident from the virulence of the attack on buds as well as from the fact that infections make little headway on mature leaves.

The spots on the leaves vary in size from minute stomatal infections to ragged, brown, irregular areas extending several inches along the blade, usually between midrib and margin (Pl. 32, 33). Small stomatal infections are found in great numbers near the margins of large spots or on leaves with no large lesions, and on mature leaves they do not develop further. On young leaves they enlarge into spots which tend to run between the parallel veins, giving to the leaf a striped effect. This effect is continued in the uneven margins of large spots formed by the coalescing of small ones, where often a diseased strip between two veins runs an inch or more beyond the main diseased area into otherwise healthy tissue. Young infections and the advancing edges of larger spots are first water-soaked, then yellow, later becoming brown. In the early morning water-soaked streaks extend far beyond the yellow tissue. Old spots are dry, thin, and grey-brown, and by shrinking cause distortions of the leaves (Pl. 32, 33). They show a dark, almost black, mottling or checkering, which is more plainly seen by transmitted than by reflected light, the

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different colored areas being rectangular rather than round. This mottled appearance and the position of the spots between midrib and margin clearly distinguish this disease from the common dying back of the older leaves, where the margin is first to succumb and the dead areas are a uniform red-brown.

Infection usually takes place while the leaves are still rolled in the bud. In case stomatal infections occur just before the leaf pushes up, the whole bud often looks very pale, almost white, and close examination shows it to be covered with minute white spots. Sometimes these do not spread further, and the leaf as it matures becomes green with a peppering of tiny spots, but more often as it unfolds it remains pale and stunted. At other times the infection has progressed so far that by the time the folded leaf emerges it is wholly or in part blackened, sometimes in spiral bands (Pl. 35, B). In such cases the younger leaves usually become infected by direct contact, or the disease runs down the petiole and kills the young stalk and bud. A non-fatal bud infection is shown in Plate 35, A, where blackening has occurred but not to such an extent as to kill the shoot.

From leaf-blade infections (Pl. 33; 36, C) the bacteria invade the petiole, not by way of the vascular system but through the parenchyma, chiefly through the channels of very loose tissue which occupy a large portion of the interior of the petiole. In the tightly rolled buds infection appears to pass directly from one leaf to another, so that when a young shoot is cut across near ground level, several petioles may be found to be diseased. The buds do not become soft-rotted but usually stand up black and dry or are bent over or broken off. Eventually the center rots out, leaving the hollow stalk standing with one or two mature leaves. This when cut across near the base is found to contain a watery rot. The rootstocks have never been found to be diseased. In the autumn of 1919 when the plants in the grounds were lifted for winter storage all the plants of one large bed that had shown heavy infection were thoroughly examined. All stalks were cut across a few inches from the ground, and in a large proportion of the clumps one to four stalks were found with interiors rotted out, to or below ground level, the lower part of the cavity being filled with fluid. In no case, however, was the rot found extending into the rootstock, the tissues of which do not seem to favor the growth of the organism. In many stalks showing a characteristic top—that is, standing erect with older leaves intact but with a hollow blackened center, the decay had not reached the lower part, so that a cross section 1 foot from ground level showed only sound tissue.

Often when the shoot has escaped early and complete destruction, the flower clusters are ruined either by the infection of the young flower buds or by the decay of the stem. In the former instance the stem and pedicels develop but the buds blacken and die while still rudimentary (Pl. 34, A, C). In the latter case the stalk bends or breaks in the infected

region (Pl. 34, B). Infection often remains on one side of the stalk, which blackens and, if infected very young, fails to elongate like the healthy side and so cracks across at frequent intervals, the cracks becoming gummy with the exuded sap (Pl. 36, C). Sometimes the rot extends along the stalk to its tip, blackening pedicels and well-formed buds.

SUSCEPTIBLE VARIETIES

During the summer of 1918 most of the varieties observed were healthy or showed only a trace of this disease. The badly affected sorts were Princeton, Gayety, City of Portland, and Charles Lutz. The disease was most virulent in the early summer, many plants recovering during August.

In 1919 the outbreak was much more virulent than in the preceding year, but the susceptible varieties were different. This time the Yellow King Humbert, a sport from the Red King Humbert, and Carmine Beauty were most injured. Many of the varieties planted in 1918 were not set out in 1919, so no comparison could be made. It was learned from one of the gardeners that some varieties had been dropped in the past because of this budrot, among them Fire Bird and Mrs. Alfred Conard. Another gardener ascribed all the trouble to overwatering and crowding in the hothouse before setting-out time, conditions undoubtedly very favorable to the activities of the causal organism.

DAMAGE DONE

In 1919 the disease was observed earlier than in the previous year—that is, in the latter part of May soon after the plants were set out. At this time there were only scattering infections, a few large leaf spots, and several infected and dead shoots. Later (June 19) several beds showed from 10 per cent to 80 per cent of infected plants; of these many had two or three of the four shoots involved, and eight plants in one bed had bent blossom stalks.

During July many plants outgrew the disease by sending out new, vigorous shoots; but in August, although to the casual observer no traces of disease were present, a great many unsightly leaves and some sickly young shoots might be found, and often a blossom stalk pushed up through a ragged brown sheath.

In May, 1920, potted plants in the hothouse ready for setting out were examined, and the following varieties were found severely infected—that is, with a scattering of dead or diseased buds: Yellow King Humbert, Gayety, Golden Eagle, Dazzler, Favorite, and Wallace.

Other varieties on the same bed and subject to the same conditions were entirely free from signs of the disease. These were Meteor, Olympic, Rosea Gigantea, Fenal, President, Princeton, and City of Portland.

No connection could be traced between infected beds of one year and the serious attack of the following year. The beds most heavily infected in 1918 were in some cases almost disease-free in 1919, others were badly

infected, while some beds where no disease occurred in 1918 showed the highest percentage of infection in 1919. These observations, however, are complicated by the fact that different varieties, the susceptibility of which is not known, were planted the second year. From present knowledge it seems that the disease must be carried over on the rootstocks, especially since the trouble begins to develop before the plants are taken from the hothouse.

Overwatering of the foliage appears to be a large factor in the development of the disease, since rootstocks which were taken from heavily infected clumps and kept under favorable conditions during the winter and carefully watered when potted in early spring gave not a single case during the entire summer, while rootstocks from the same source without special care showed a large percentage of infection before setting-out time.

GEOGRAPHICAL DISTRIBUTION

The disease has thus far been observed only in the District of Columbia and in Illinois. Typically infected plants were found at Urbana, Ill., in the summer of 1920.

ISOLATIONS

When sections were made of diseased tissues, motile bacteria were invariably found in great numbers swarming out on the slide. Plates were poured on peptone-beef agar from leaf spots, pedicels, and from petioles near the ground level. In every case practically pure cultures of a white bacterial organism were obtained. Judged from plate colonies, the organism was the same in every case, and comparative cultural studies of several isolations have corroborated this judgment.

INOCULATIONS

Inoculations were made in 1918 on potted cannas in the hothouse. These plants were not in good condition but were the only ones available at the time. Young leaves just unfolded were inoculated by placing drops from a young agar slant culture on the surface and making delicate pricks in the blade through these. Drops were also poured into the tips of tightly rolled leaves without wounding. Subcultures of isolations from leaf blades and from petioles were used. Some plants were kept moist for 36 hours by spraying in cages with sterile water; others were left in the open hothouse.

In most cases no infections appeared. One inoculated leaf showed on the fourth day several water-soaked streaks 1 to 10 mm. long running from needle pricks. These turned yellow then brown, but did not spread further. Plates were poured from the edge of the longest streak, and colonies were obtained which appeared to be right. Transfers from these conformed to the original isolation in subsequent cultural tests.

Attempts were made to infect the slow-growing cannas with the reisolation recorded above, but all of these failed. Further inoculation

work was therefore postponed until the following spring, when more favorable conditions would obtain.

When the disease appeared in 1919, isolations were made from active young infections on leaves and petioles; and single colony subcultures from these were used for inoculating young vigorous cannas, obtained from a new source, in large pots in the hothouse. Suspensions from young agar cultures were sprayed into the youngest rolled leaf of some plants without wounding. In other cases the stalk below the lowest leaf blade was smeared with bacteria, and pricks were made through this to the young leaves within. Part of the inoculated plants of each lot were kept in cages and sprayed with sterile water for 36 hours; others were left in the open house. Controls in other cages were sprayed with sterile water.

Good prompt infections were obtained by both spray and prick inoculations on the plants that were kept in cages, and only fair infections on those in the open house that were pricked. Controls remained healthy. Infection was apparent on the sprayed plants only when the young, susceptible leaves which were tightly rolled at the time of inoculation emerged or unrolled, usually after six or seven days. On the oldest rolled leaves those spots which at this time showed as small stomatal infections did not progress further. On younger leaves the initial stomatal stage was past, the spots extending from vein to vein and beginning to lengthen into streaks (Pl. 36, A). On pricked plants kept in cages, infection was more rapid and destructive, as is shown on Plate 36, B, C. Here infection showed on the fourth day, running downward from pricks seen in the photograph near the tips of the leaves (X, X). These leaves were tightly rolled when pricked through the enveloping folds of older leaves. In the leaf shown on Plate 36, C, the streak from the pricks on the midrib was 3 cm. long on the fourth day. One day later it was 10 cm. long, and by the eleventh day it had reached almost to the base of the next older leaf, widening downward where inclosed by the sheathing petioles and killing the shoot completely. After the plants were once infected, secondary infections took place in some cases on young shoots which were in the same pots with inoculated shoots but which were too young at the time of inoculation to have been directly infected—that is, were without any leaf which had begun to unfold. Younger unfolding leaves on sprayed shoots also showed infection as they emerged some weeks later.

From several of these infections reisolations were made, and inoculations with single colony transfers thus obtained gave typical infections on cannas when inoculated by spraying and by needle pricks. These isolations and reisolations were used for cultural work in comparison with cultures of the previous year, with which they were found to agree.

THE ORGANISM

DESCRIPTION

The causal organism is a short rod with rounded ends, single, in pairs or chains, 1 to 2 μ long by 0.5 to 0.7 μ broad, when stained from 24-hour agar cultures. It is motile by means of one to three bipolar flagella (Pl. 38, B). It does not form spores, is Gram-negative, is not acid-fast and stains readily with the ordinary anilin stains. Capsules were stained from 10-day agar cultures with Ribbert's stain. Rods with swollen ends occur in old milk cultures.

CULTURAL CHARACTERS [1]

AGAR PLATES.—On +15 (Fuller's scale) peptone-beef agar at 20° to 25° C., colonies appear on the second day. By the fourth day the surface colonies are 2 mm. in diameter, thin, white, round with entire margin, wet shining, finely granular, semitransparent, with internal concentric markings by oblique light, especially in the thinner margins. As colonies enlarge (5 to 8 mm.) they are white, slightly convex, and may be either round or irregularly scalloped (Pl. 37, C). The scallops are formed by wedges of more transparent growth in which distinct radiating lines are seen by direct transmitted light (Pl. 38, D). By oblique transmitted light the wedges show both radiating lines and also internal concentric markings (Pl. 38, E). In consistency they are viscid, becoming more so with age. Buried colonies are lenticular, becoming round to irregular.

AGAR STABS.—In agar stabs the surface growth is flat, wet shining, moderate, at first round, later with an undulate margin, then covering the entire surface. Stab growth is moderate, granular, tapering downward, ending at one-half the depth of the agar. In old cultures crystals form from the surface downward in ragged spears 1 to 2 cm. long. There is no discoloration of the agar.

AGAR STREAKS.—Two-day-old streaks from bouillon are filiform, 2 mm. wide, tapering upward, white, wet shining, with thin margins and granular center. Later (6 days old) growth is 4 to 5 mm. wide with finely scalloped edges and radiating lines by transmitted light, running from the granular center into the translucent margins. The V is half filled with white precipitate. The growth is very viscid.

GELATIN PLATES.—On gelatin plates kept at 15° C. colonies appear on the fourth day. At 20° they are visible on the second day. Growth is very slow and without liquefaction at 15°. Colonies are thin, round, later becoming flower-like—that is, with a crater-like center and wider scalloped margin (Pl. 38, C). At 21° to 24° very slow liquefaction occurs, beginning about the tenth day, especially on thickly sown plates. On thinly sown plates colonies usually lie in a shallow, dry saucer.

[1] Kahlbaum's agar and Difco peptone were used throughout.

GELATIN STABS.—There is slight granular growth along the entire line of puncture, best at the top where it is sometimes villous or papillate, the length of the villi or papillae decreasing downward. Surface growth when 6 weeks old at 15° to 18° C. is thin, white, transparent, slightly rugose, with an undulate margin. No liquefaction occurs within two months at this temperature, but at 21° to 25° a saucer of liquefaction 1 cm. deep may be formed within three weeks. Usually clusters of crystals form at the bottom of the liquefied part.

WHEY AGAR [1] PLATES.—Colonies on whey agar plates are white, round, convex, opalescent, with internal concentric markings by oblique light. On thickly sown plates by the third day, and on thinly sown plates by the fourth or fifth day, each colony is surrounded by a clear area 1 to 2 mm. wide, beyond which a white halo extends outward (Pl. 37, B). On thickly sown plates this involves the whole surface. As the colony grows it fills the clear space, even growing out into the white halo. The halo is composed of an alkaline precipitate, which is readily dissolved by acids.

WHEY AGAR SLANTS.—Streaked from beef bouillon, growth is moderate, white, filiform, 2 to 4 mm. wide with undulate margins. The whole surface of the agar becomes white-clouded except for a clear area 1 to 4 mm. wide closely surrounding the streak of growth (Pl. 37, D). This halo is dissolved by acids.

POTATO CYLINDERS.—Growth on steamed potato is scanty, spreading, dirty white, wet shining, transient, becoming pale brown. The potato is grayed. Diastasic action is feeble.

BEEF BROTH.—Peptonized beef broth (+15) clouds weakly within 24 hours at room temperatures (21° to 25° C.); often within this time it forms a heavier flocculent surface layer, which falls on the slightest agitation. In undisturbed cultures the clouding is often banded, the heavier bands at the top. A heavy, viscid pellicle forms, which often falls slowly, center first, the edges remaining attached to the walls, so that a hollow inverted cone is formed (Pl. 37, A), which lengthens slowly to reach from pellicle to precipitate, and may persist for weeks. This occurs in both alkaline and acid bouillons. The abundant viscid precipitate is granular, semitransparent, and does not form a compact mass. It rises in a tenaciously viscid swirl on shaking. Clouding becomes heavy and is persistent.

MILK.—Milk begins to clear on the fifth to the tenth day, and clearing is complete within four weeks. No coagulation takes place. The milk becomes golden brown on long standing, sometimes with a jelly-like consistency.

[1] Formula for whey agar: To 3 pints of milk heated to boiling add a 20 per cent solution of hydrochloric acid sufficient to coagulate the milk. Avoid excess of acid. Filter through cheesecloth. Add *N*/4.5 sodium hydroxid until the whey titrates +7. To 500 cc. of whey add 150 cc. of water, 1.5 gm. of Nelson's photographic gelatin No. I, 7.5 gm. of peptone, 7.5 gm. of agar flour, and 7.5 gm. of saccharose. Dissolve by steaming 20 minutes, clarify with white of egg, tube, and autoclave 15 minutes at 110° C.

LITMUS MILK.—Litmus milk blues rapidly and uniformly from the top downward, beginning on the second day. There is no coagulation, but a gradual uniform clearing. Reduction begins promptly, the color passing from blue to pale purplish gray (Ridgway,[1] *Pl. LIII*), drab gray (Ridgway, *Pl. XLVI*), light drab (Ridgway, *Pl. XLVI*), and tawny olive (Ridgway, *Pl. XXIX*). Later the blue color returns.

METHYLENE BLUE MILK.—Milk to which methylene blue was added to make it robin's egg blue shows reduction in color on the second day. In 10 days reduction is complete.

COHN'S SOLUTION.—Usually no clouding occurs in Cohn's solution. Occasionally very weak clouding takes place and a faint rim is formed. After six weeks in such cultures the fluid is clear with 3 to 6 mm. width of white precipitate which breaks up on shaking.

USCHINSKY'S SOLUTION.—In Uschinsky's solution clouding is heavy with a viscid pellicle falling like that in beef broth, and a heavy viscid precipitate.

FERMENTATION TUBES.—In fermentation tubes containing 1 per cent peptone plus 1 per cent saccharose, dextrose, lactose, maltose, glycerin, or mannit there is good clouding in the open end, but none in the closed end, and no gas. All give a slightly alkaline reaction to neutral litmus paper at the end of two weeks.

LITMUS SUGAR AGAR.—Litmus agar containing 1 per cent peptone water plus 1 per cent saccharose, dextrose, lactose, maltose, galactose, or glycerin is not reddened. Moderately good growth occurs on all.

BLOOD SERUM.—Growth on blood serum is moderate, with no liquefaction and no discoloration of the medium.

CONGO RED AGAR.—On congo red agar little or no growth occurs, but in a few cases it was sufficient to show that the red color is taken up by the organism.

OPTIMUM REACTION FOR GROWTH IN BOUILLON.—The organism grows best in +10 to +15 peptone-beef bouillon. It grows fairly well in +20 to +25 but not at all in +30. Growth is good in neutral bouillon and in −5 to −10, is weak in −15, very weak in −20, and no growth occurs in −25.

TOLERATION OF ACIDS.—Neutral peptone-beef bouillon was used, to which was added 0.1 per cent, 0.2 per cent, and 0.3 per cent of malic, tartaric, and citric acid, respectively. These titrated as follows:

Malic	0.1 per cent	+18	Tartaric	0.1 per cent	+23	Citric	0.1 per cent	+24
	.2 per cent	+32		.2 per cent	+37		.2 per cent	+40
	.3 per cent	+47		.3 per cent	+53		.3 per cent	+53

The organism grew readily in 0.1 per cent of all three acids, best in the malic, and weakest in the citric. No growth took place in 0.2 per cent or in 0.3 per cent of any of them. Other tests were made with

[1] RIDGWAY, Robert. COLOR STANDARDS AND COLOR NOMENCLATURE. 43 p., 53 pl. (col.). Washington, D. C. 1912.

the following results: Growth in +32 malic acid, +37 citric acid, and +35 tartaric acid; no growth in +33 malic acid, +40 citric acid, and +37 tartaric acid.

TOLERATION OF SODIUM CHLORID.—Tests were made in +15 peptone bouillon to which were added 1, 2, 3, 4, and 5 per cent sodium chlorid. Prompt clouding, becoming heavy, appeared in 1 per cent, and fairly prompt moderate clouding appeared in the 2 per cent. The growth in 3 per cent was delayed and took the form of cobwebby, viscid, persistent, streamers without clouding. These streamers were not made up of chains but of single or paired organisms. No growth occurred in the presence of 4 or 5 per cent sodium chlorid.

OTHER CULTURAL FEATURES.—Growth is not retarded in bouillon over chloroform. Nitrates are strongly and promptly reduced. No indol is formed (10 days to 2 months). Hydrogen sulphid is produced in peptone-beef bouillon. Ammonia production is strong. The odor of most cultures is rather disagreeable.

TEMPERATURE RELATIONS.—The optimum temperature for growth is about 35° C. No growth takes place in peptone-beef bouillon (+15) below 5° nor above 40°. In one test there was very weak growth at 40°. The thermal death point is 52°.

EFFECT OF FREEZING.—When transfers from young +15 peptone bouillon cultures are frozen solid and kept frozen for 15 minutes, then thawed and plates poured with measured loops just as before freezing, the colony counts show that from 50 to 90 per cent are killed.

EFFECT OF DESICCATION.—The organism is very sensitive to drying. Drops of 1- to 6-day-old bouillon cultures were dried on cover glasses in sterile Petri dishes in the dark. These covers transferred to bouillon after 2 days' drying gave prompt clouding; after 3 days less than half gave growth, and after 5 days no growth was obtained.

EFFECT OF SUNLIGHT.—The organism is very sensitive to sunlight. Agar poured plates, one-half covered with black paper, were exposed to bright sunlight bottom side up on ice in November at 11.30 a. m. When counted 5 days later, colonies were numerous on the covered side. On the exposed side there was noticeable reduction after 1 minute's exposure; 75 per cent were killed after 2 minutes, 95 per cent after 3 minutes, and all were killed after 4½ minutes' exposure.

VITALITY ON CULTURE MEDIA.—The most long-continued growth is made in milk, peptone-beef bouillon, and peptone-beef agar. At room temperatures the organism will live in these media for 6 or 7 months, or until the medium is almost completely evaporated. Cultures in these media kept in the ice box for 1 year give prompt growth when transferred.

GROUP NUMBER

According to the chart of the Society of American Bacteriologists [1] the group number of this organism is 211.3333023.

TECHNICAL DESCRIPTION

Bacterium cannae, n. sp.

A short rod with rounded ends; chains; flagella 1 to 3, bi-polar; capsules; no pseudo-zoogloeae; aerobic; nonchromogenic; liquefies gelatin very slowly; diastasic action weak; reduces nitrates; does not produce acid or gas from sugars; clears milk; blues, then reduces litmus milk without coagulation; does not produce indol; produces hydrogen sulphid and ammonia; grows in Fermi's and Uschinsky's solutions and very feebly or not at all in Cohn's solution; optimum temperature 35° C., maximum 40°, minimum 5°; thermal death point 52°; vitality at room temperatures on media six months; Gram-negative, not acid-fast; sensitive to drying; moderately tolerant of acids and alkalis; sensitive to freezing and to sunlight. The cause of a meristematic disease cultivated in cannas.

SUMMARY

The budrot of cannas is a hitherto undescribed bacterial disease caused by *Bacterium cannae*, n. sp. The disease is primarily one of young tissues and moist conditions.

Infection takes place through the stomata and spreads through the intercellular spaces of the parenchyma of leaf blade, petiole, and stalk.

It is most destructive early in the season, that is on young plants. It begins in the hothouse and continues in the open beds. It destroys the buds, forms large unsightly spots on the leaves, and ruins the blossom clusters by blighting the flower buds or by decaying the stalk.

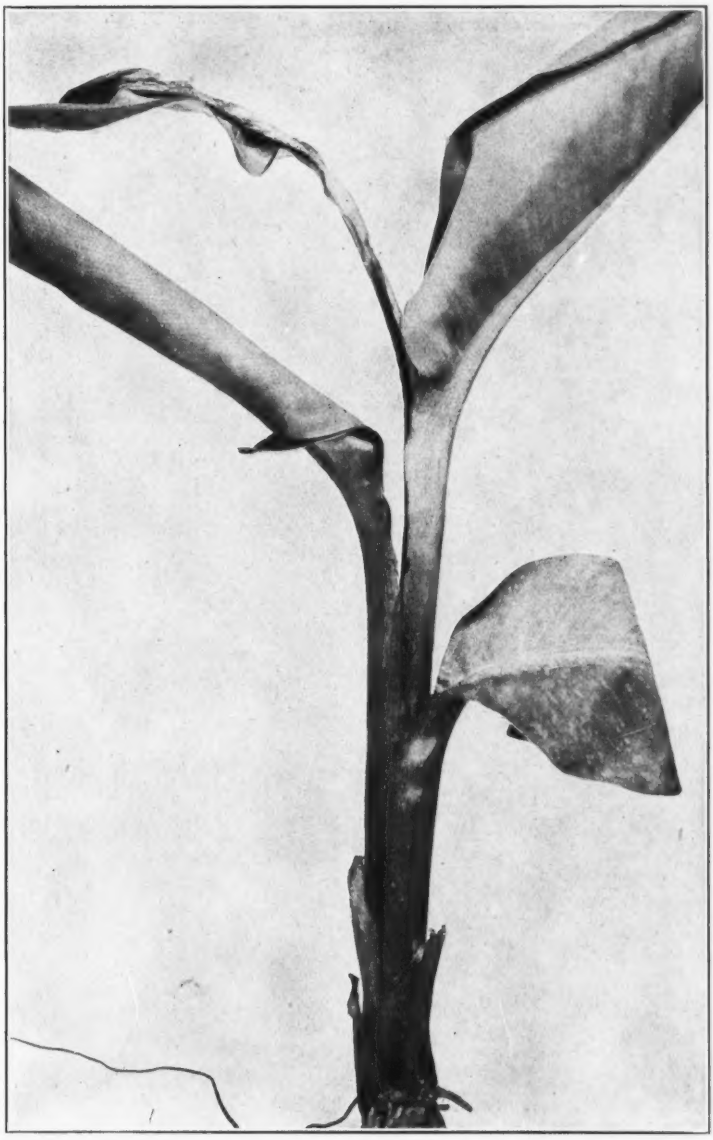
The method of overwintering whether in the soil or on the rootstocks, or both, is uncertain as yet. Although no means of control has been worked out, it is recommended as a preventive measure that rootstocks for planting be selected as far as possible from healthy stock only, that care be observed to avoid crowding and overwatering before setting out, that good ventilation be maintained in the houses, and that specially sensitive varieties be discarded.

[1] SOCIETY OF AMERICAN BACTERIOLOGISTS. DESCRIPTIVE CHART. Indorsed by the society for general use at the annual meeting Dec. 31, 1914. Prepared by the committee on revision of chart identification of bacterial species.

PLATE 31[1]

Young canna shoot (natural infection) in which the bud has been killed. *Bacterium cannae* was plated from the interior 1 inch from the base of the shoot. Root-stock healthy.

[1] All photographs in Plates 31 to 38 are by Mr. James F. Brewer.



A Bacterial Budrot of Cannas

PLATE 32

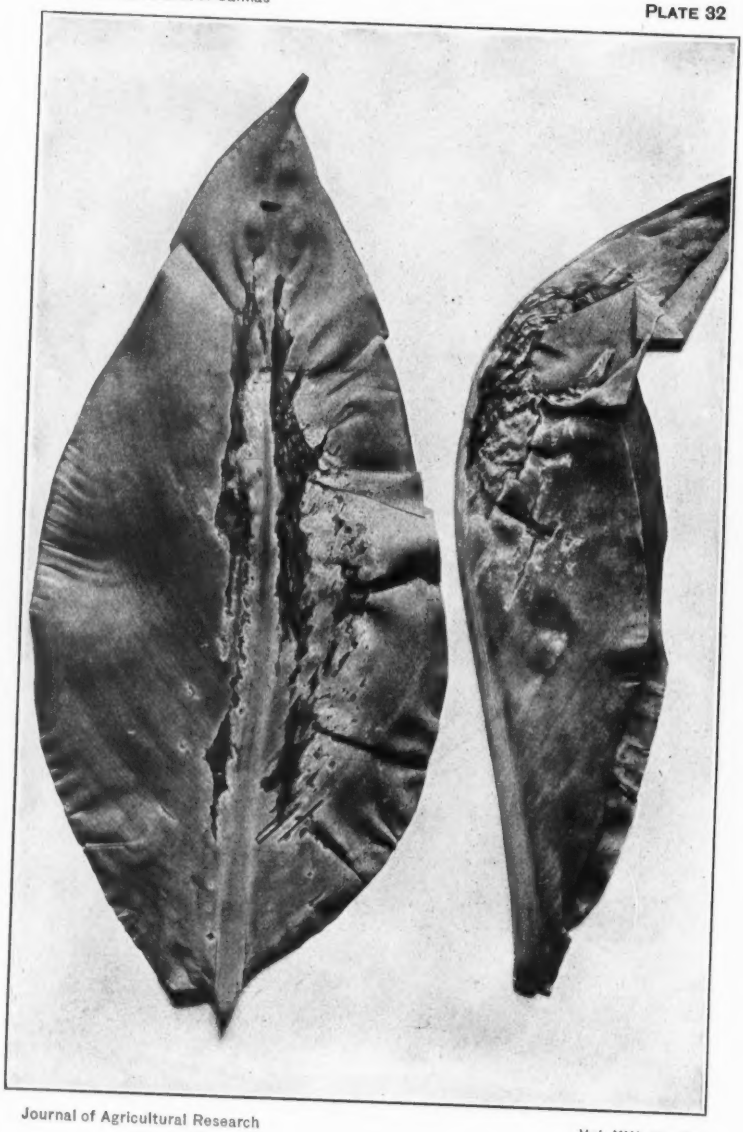
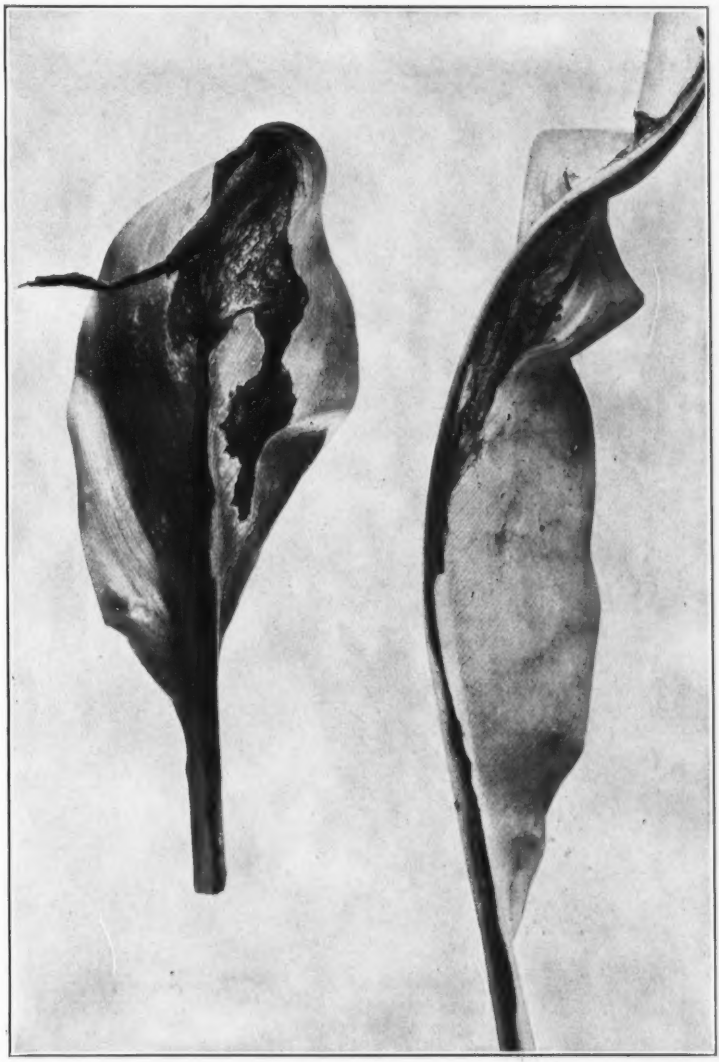


PLATE 32

Canna leaves (natural infection), showing character of spots and distortion of leaves. These were put under glass to straighten sufficiently for a photograph. Note lighter (yellowed) areas and minute stomatal infections in the vicinity of large spots. Much reduced.

PLATE 33

Canna leaves (natural infection), showing disease running down the petioles from large leaf spots. Compare Plate 36, A, where the infection is just reaching the midrib.



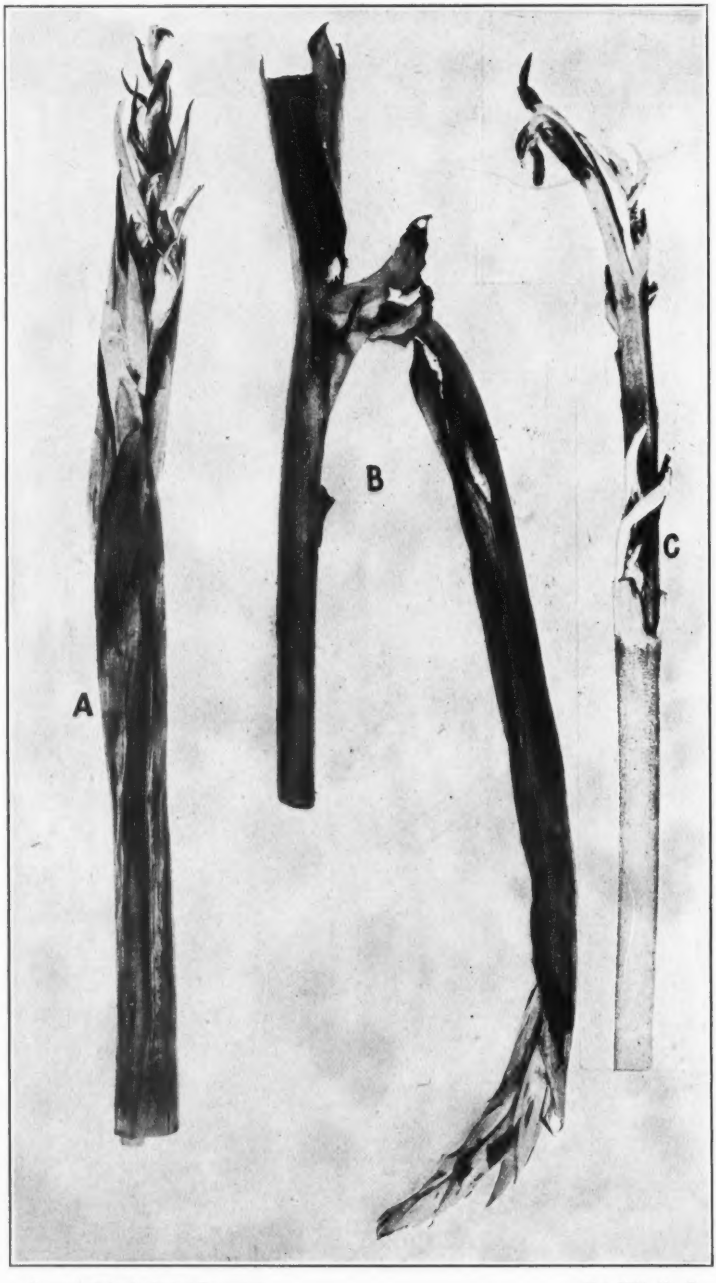

A
B
C

PLATE 34

Blossom clusters (natural infection).

A, C.—Infection on the blossom buds (blackened) of uninjured stalks.

B.—Stalk decayed on one side and broken over while the buds are only slightly infected.

PLATE 35

Tightly rolled buds showing infection.
A.—Bud moderately infected, and next older leaf with infections at base and at tip.
B.—Badly infected bud. Entire blackened area diseased.
Natural infections.

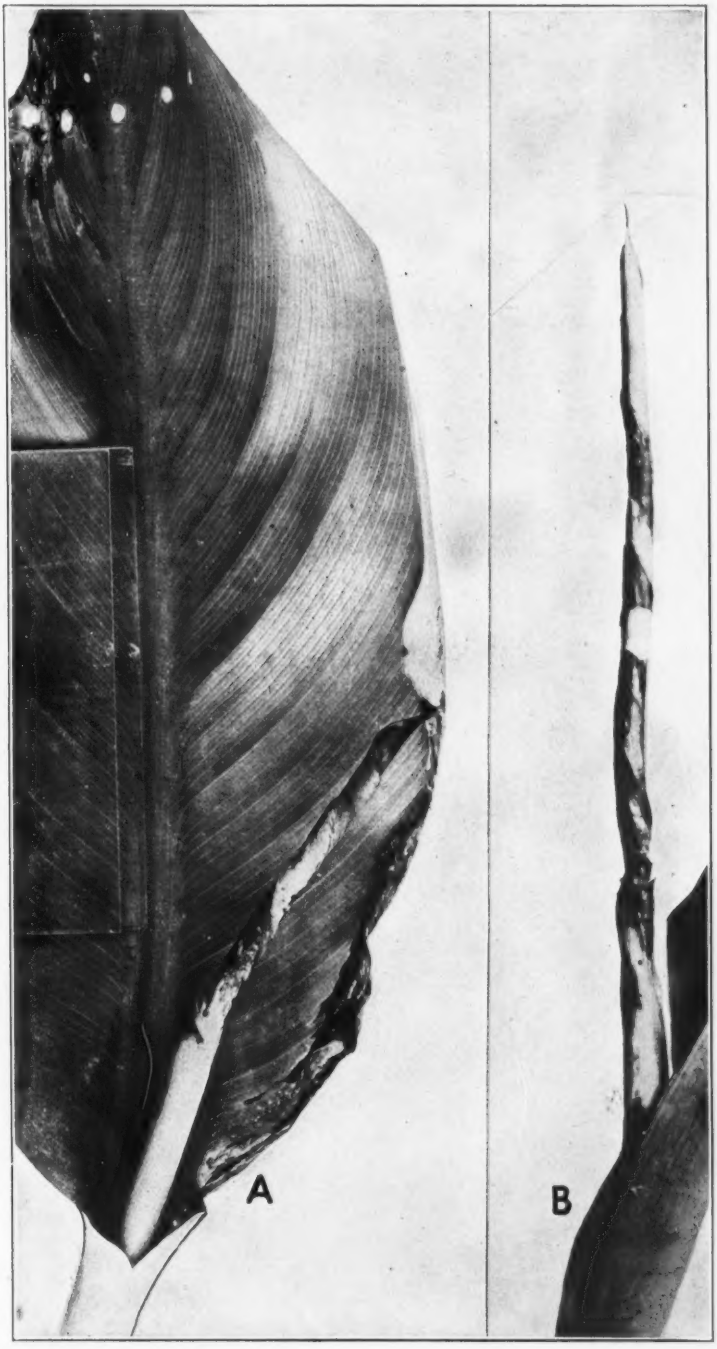

A
B

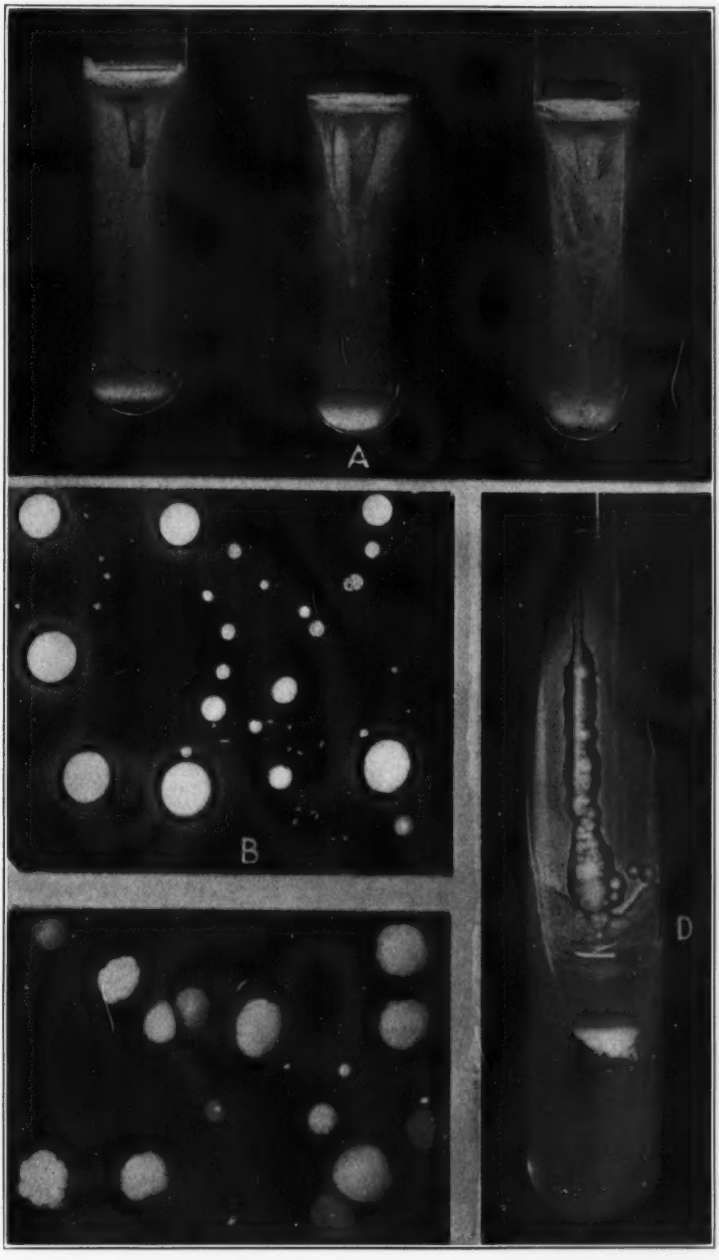
PLATE 37

A.—Cultures in + 10 beef bouillon, 8 days old, showing viscid, persistent, falling pellicle in different stages.

B.—Colonies on 8-day-old whey agar plates. × 2.

C.—Colonies on beef agar 11 days old, showing shape. × 2.

D.—Whey agar slant 3 days old, showing clear area and alkaline halo.


A
B
D

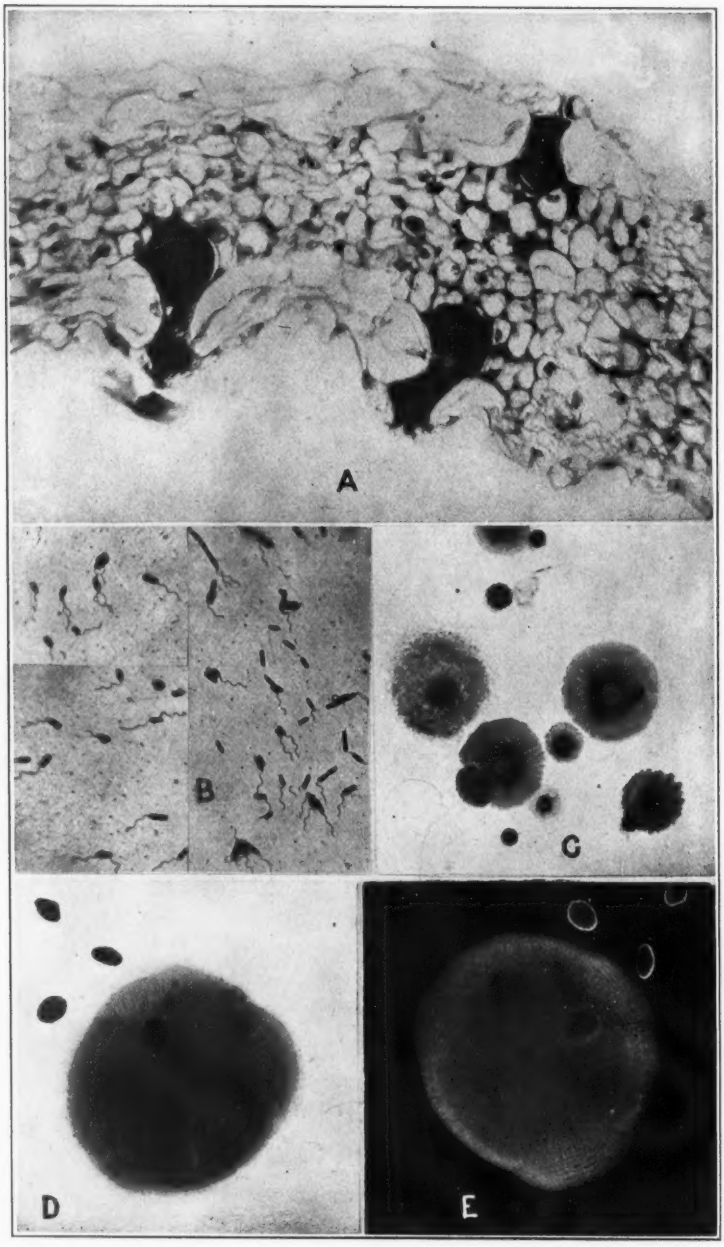

A
B
C
D
E

PLATE 38

A.—Section of young leaf with stomatal infections. Bacteria have penetrated the intercellular spaces to the center of the leaf from the upper infection at the right. The cloud below the lower left infection is composed of bacteria. Stained with Ziehl's carbol fuchsin.

B.—*Bacterium cannae*, showing flagella. × 850.

C.—Colonies on gelatin plate 7 days old at 15° to 18° C. × 10.

D.—Agar plate colony by direct transmitted light, showing radiating lines and 3 buried colonies. × 10.

E.—Same colony as in D but by oblique transmitted light, showing internal concentric markings and radiating lines. × 10.

A CHLOROSIS OF CONIFERS CORRECTED BY SPRAYING WITH FERROUS SULPHATE

By CLARENCE F. KORSTIAN, *Forest Examiner*, CARL HARTLEY, *Pathologist*, LYLE F. WATTS, *Forest Examiner*, and GLENN G. HAHN, *Scientific Assistant, Forest Service and Bureau of Plant Industry, United States Department of Agriculture* [1]

INTRODUCTION

In plants the term "chlorosis" is commonly applied to any abnormal condition whose most conspicuous symptom is a deficiency of green pigment. An exception to this general statement is perhaps the albinism of seedlings of oak, pine, and other plants which are from the first entirely lacking in chlorophyll, or, as sometimes happens in the conifers, have green cotyledons but no green in the leaves formed later. While such plants have always, so far as the writers' experience goes, died in the seedling stage, and the phenomenon must therefore be regarded as strictly pathological, the condition is not ordinarily spoken of as chlorosis. The inherited tendency on the part of healthy plants of horticultural varieties to grow leaves or parts of leaves lacking in chlorophyll is not usually considered pathological, and is better known as "variegation" than as chlorosis. True chlorosis may be due to a number of causes, such as low temperature, which hinders the formation of pigment, or lack of nitrates, which, according to Crocker (*2*),[2] at least in one of the algae, is associated with a rapid decomposition of chlorophyll. Plants in full sunlight are often less green than those less exposed, probably because of the rapid disintegration of the pigment in strong light. High temperatures very likely have the same effect (Blackman's "time factor"). Plants with deficient water supply are, on the other hand, liable to chlorosis caused by difficulty in pigment synthesis.

Much study has been given to the chlorosis of plants on calcareous soils, especially in connection with grapes in Europe. Roux (*18*) lists a large amount of literature on this subject. Recent papers by Mazé, Ruot, Lemoigne (*13*), and Gile (*6*) are well worth attention. The favorable effect of iron on plants affected with certain types of chlorosis was discovered before the middle of the last century, spraying a solution of an iron salt on chlorotic leaves having resulted in correcting the chlorotic appearance (*24*). Molisch (*14*) discusses many of the earlier experiments with iron. In a recent interesting paper, Johnson (*12*) states that spraying with iron salts is helpful for a chlorosis associated with extremely high

[1] The writers wish to acknowledge helpful suggestions from Dr. C. B. Lipman and Dr. Howard E. Pulling.

[2] Reference is made by number (italic) to "Literature cited," p. 170–171.

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manganese content of the soil. Dementjew (*4*) discusses the question of whether chloroses corrected by iron are really cases of iron hunger.

The literature on the chlorosis of conifers is relatively small. Sorauer (*23*) has reported chlorosis in *Thuja occidentalis* in Europe, and Schmuziger (*21*) and Dafert and Kornauth (*3*) have noted chlorosis in spruce, without attempting to connect it with causal factors. Schmuziger reports, as do other observers on angiosperms, that the chlorotic leaves contained plastids which became green when the leaves recovered. Neger (*16*) has described in more detail a chlorosis of spruce in a cold autumn in which the yellow leaves or parts of them were found to contain much more starch than the green leaves or their green bases with yellow tips. He rather vaguely connects both current low temperature and the drouth of the preceding winter with the various phenomena observed.

Contejean (*1*) lists Scotch pine (*Pinus sylvestris*) as somewhat calcifuge, and makes the general statement that excess lime accompanied by lack of iron, or "encore plus" lack of potassium, results in chlorosis of calcifuge plants. He, however, makes no specific mention of chlorosis in any conifer. Fliche and Grandeau (*5*) attribute the calcifuge tendencies of *P. sylvestris* to the physical rather than the chemical qualities of lime soils. They find Austrian pine (*P. austriaca*), *P. halepensis*, and *Abies pectinata* doing well on strongly calcareous soils, but they find *P. pinaster* making a poor growth in plantations on calcareous soil in all cases observed and entirely refusing to grow in some cases. Deficiency in starch and chlorophyll are noted for this pine on the lime soils, and also to a very slight extent for the Austrian pine on soils with extremely high calcium-carbonate content. The chloroplasts of the chlorotic plants are said to be small. The poor condition is attributed to potash hunger, and no mention is made of iron hunger as a possible cause. Ash analyses showed the following conditions:

On good soil,

Pinus pinaster, potash 16 per cent, iron oxid 3.8 per cent, lime 40 per cent.

On excessively calcareous soil,

Pinus pinaster, potash 5 per cent, iron oxid 2.1 per cent, lime 56 per cent.

Pinus austriaca, potash 14 per cent, iron oxid 3.3 per cent, lime 49 per cent.

Sachs (*20*) reports chlorosis in young trees of *Abies balsamea*, *A. apollonis*, and *A. bicolor* and says that entirely chlorotic new growth becomes green more or less promptly after considerable quantities of solid iron sulphate are placed in ditches in the soil near the roots. No controls are mentioned, but the promptness with which the younger trees are reported to have responded to the treatment supports his conclusion that the recovery was due to the iron added, despite the fact that fast-growing chlorotic shoots, according to his own statement,

usually improve in color toward the end of the season without any special treatment.

An interesting American report is that on chlorosis of *Sequoia sempervirens* by Peirce (*17*).

CHLOROSIS OF CONIFER NURSERY STOCK IN THE UNITED STATES

At several of the nurseries of the United States Forest Service in Nebraska and farther west, conifers are occasionally somewhat chlorotic The condition has become a matter of importance, however, only in the Morton Nursery, in northwestern Nebraska, and the Pocatello Nursery, in southern Idaho. Chlorosis has also been noted in conifers at the Great Basin Experiment Station in central Utah, especially in lodgepole pine (*Pinus contorta*) seedlings and transplants grown two years in the seed bed and one year in the transplant bed. At the latter locality native aspen (*Populus tremuloides*) was also chlorotic in places.

ANALYSES OF SOIL AND WATER

At all the points at which chlorosis was found, analysis (by courtesy of the United States Bureau of Soils for the nursery soils, and of Dr. J. E. Greaves, of the Utah Agricultural Experiment Station, for the Great Basin Experiment Station soils, showed the presence of carbonates as indicated by carbon-dioxid evolution. Carbon dioxid was, however, reported from sites near the Great Basin Experiment Station on which no chlorosis had been observed in either aspen or conifers, and from a nursery at which chlorosis had never been serious. In some cases the amount reported from soils on which the trees were green was greater than from those where the trees were chlorotic. The acid-digestion analyses showed for all the soils on which chlorosis was observed a considerable amount of calcium, much greater than that ordinarily found in the humid region of the United States, and in every case greater than the average of the 570 soils of the arid region reported by Hilgard (*10, p. 377*). However, there is little apparent correlation between the amount of chlorosis and the amount of calcium reported. The Utah soil on which conifers were not chlorotic yielded over 17 per cent of lime (as CaO) and 12½ per cent of carbon dioxid. The Pocatello nursery soil on which chlorosis was serious yielded more than twice as much calcium (2.9 to 4.7 per cent CaO) as Hilgard's average for arid soils. It was not an excessively calcareous soil, however, as compared with some of the soils reported in connection with chlorosis in Europe and Porto Rico, with the chalk soils reported by Somerville (*22*) on which healthy Douglas fir was growing, or with the Utah soil just mentioned as supporting normally green conifers. The phosphorus (as P_2O_5) for the Pocatello soil was reported as approximately 0.7 per cent for all the samples, an unusually high figure. This at once suggests a possible relationship, in view of the slight

solubility of ferric phosphate. The other soils on which chlorosis occurred, however, did not give any such high phosphorus analysis. The fact that the solubility of ferric phosphate is sufficient to make it a good source of iron in water-culture experiments prevents any probability of a relation between the amount of phosphorous found by analysis and the availability of iron.

All the analyses indicated normal quantities of iron. The results are in agreement with the general experience that acid-digestion soil analyses yield little information of value from the plant physiological or pathological standpoint. Petrographic examination by the United States Bureau of Soils of the Pocatello soil and of the nursery soil which contained carbonates without chlorosis gave no clue to the difference between the plants on them. Acidity determinations by Dr. L. J. Gillespie, of the Bureau of Plant Industry, showed a P_H of 7.8 for the Pocatello soil and 8.4 for the nursery at which there were carbonates but no serious chlorosis. The main facts to be drawn from the examination of the soils of the different stations was that all the soils on which chlorosis occurred contained carbonates and that two of them were underlaid with limestone.

Analysis by the United States Bureau of Chemistry of the water supply showed 320 mgm. of bicarbonic acid (HCO_3) per liter of water at the Pocatello Nursery, and practically no other anions, while at the nursery at which there were soil carbonates but no chlorosis there were reported 180 mgm. of bicarbonic acid per liter, as against 450 mgm. of sulphate (SO_4) per liter. This is of some interest in connection with the difference in the amount of chlorosis at the two places, as the arid conditions made necessary the application of considerable amounts of water to the nursery beds during warm weather. The soil solutions during the periods of greatest growth must, therefore, have been influenced to a considerable extent by the character of this water. It was noted at the Pocatello Nursery that the chlorosis was more prevalent in beds which had been under nursery management for several years than in beds which had just been included in the nursery area and had therefore received less of the water.

KIND AND EXTENT OF INJURY

At the Pocatello Nursery there was so much chlorosis and the growth of affected stock was so unstisfactory that a detailed study of it was undertaken. The nursery is at an elevation of 5,200 feet, well below the lower limit of natural coniferous forest growth in this region. Precipitation for the period during which the nursery is usually free from snow (April to October, inclusive) averaged but 11.2 inches for the years 1909 to 1917, inclusive. The days are warm and the nights cool during the growing season, only 2½ months being entirely free from killing frost. The soil is a rather heavy black silt loam; composite samples from 8 to 10

points each show for three different parts of the nursery wilting coefficients of 11.7, 12.6, and 14.3 per cent, respectively.[1]

The species in which the chlorosis has been noted are western yellow pine (*Pinus ponderosa*), Jeffrey pine (*Pinus jeffreyi*), Corsican pine (*Pinus laricio corsicana*), and Douglas fir (*Pseudotsuga taxifolia*). Of the two most important species grown here, western yellow pine and Douglas fir, the former is the more susceptible, especially during its first year. During the second year, Douglas fir is also considerably affected.

The yellowing first becomes evident in the leaves of most recent growth, as reported by Sachs (*20*) for firs and broad-leaved plants. The entire foliage may be affected. In serious cases, the leaves are short, inclined to curl, and are less turgid than normal leaves (as a consequence of lack of sugars and therefore low osmotic pressure). The terminal bud either fails to develop or is dwarfed and usually abnormally light in color. The height and diameter of the stem, the length of the roots, and especially the ability to form fibrous lateral roots also appear to suffer in typical cases of chlorosis. The disease may occur in patches, or isolated yellow plants may occur. In severe cases death ensues, the parts first discolored being the first to die.

The greater part of the injury develops after height growth has mainly ceased for the season. A marked functional disturbance is indicated in the apparent inability of chlorotic plants to harden properly for the winter. Chlorotic first-, second-, and third-year seedlings of both Douglas fir and western yellow pine, though not growing with the vigor of green seedlings, continue growth later in the season and are more susceptible to injury by early fall frosts. This recalls the frost susceptibility of chlorotic redwood shoots reported by Peirce (*17*) and further suggests a relation between chlorosis and low osmotic pressure due to failure to make sugar, as in wilting. Decreased winter loss as a result of a treatment which controlled the chlorosis is shown by the data in Table I. Seedlings chlorotic during their first or second year start growth tardily or not at all the following season. The number of dwarfed chlorotic plants which die during the summer is increasingly great during the second and third years in the seed bed. In transplanting, chlorotic seedlings are discarded.

[1] Determined by the indirect method of Briggs and Shantz in the Laboratory of Biophysical Investigations, Bureau of Plant Industry, United States Department of Agriculture.

TABLE I.—*Effect of iron-sulphate spraying on mortality of western yellow pine seedlings*

Series and plot.	Age of stock during treatment period.	Number of seedlings per square foot.	Treatments.			Dead seedlings.		
			Dates.	Strength of solution (grams per 100 cc.).	Amount $FeSO_4$ per square foot of bed.	Sept. 3 to Oct. 22, 1917.	Oct. 22, 1917, to Apr. 23, 1918. (winter-killed).	Sept. 3, 1917, to Apr. 23, 1918.
	Months.		*1917.*		*Gm.*	*Per cent.*	*Per cent.*	*Per cent.*
I, treated	14 to 18	108	Aug. 2, 24, Sept. 3, 12, 22, and Oct. 2.	2	[a] 0.95	4	0	4
II, treated	do	75		1	[a] .47	5	0	5
I, control	do	115				3	8	11
II, control	do	80				4	15	19
III, treated	2 to 5	52	Sept. 3 12, 22, and Oct. 2.	2	[a] .95	13	0	13
Do	do	58		1	[a] .47	14	0	14
Do	do	63		.5	[a] .24	14	11	24
III, control	do	76				14	9	22

[a] 0.1 pint of solution per square foot, equivalent to 0.02 inch of rain, applied to each treatment.

The prevalence of chlorosis in the Pocatello Nursery during September, 1917, was determined by examining several thousand plants of the different age classes of western yellow pine and Douglas fir. Of the first- and second-year western yellow pine seedlings 82 and 62 per cent, respectively, were chlorotic; while 74 per cent of the transplants grown two years in the seed bed and one year in the transplant bed were chlorotic. First-, second-, and third-year seedlings of Douglas fir were chlorotic to the extent of 6, 65, and 26 per cent, respectively; while 15 and 62 per cent of the transplants grown three years in the seed bed and one and two years, respectively, in the transplant bed were chlorotic.

EFFECT OF WATERING

It was at first thought that too heavy watering might have been responsible for the chlorosis at the Pocatello Nursery. While an examination of the condition of the soil did not indicate water-logging, variations in the amount of artificial watering were tested. Four plots of Douglas fir seedlings approximately 2 months old were given varying amounts of water throughout a period of slightly over two months. The results appear in Table II. The artificial watering was at first given approximately once a week and amounted to the equivalent of 0.55 inch of rain on plot D, the most heavily watered plot. Plot C received two-thirds of this amount, plot B one-third, and plot A none. After the first month the amount of water added at each watering was decreased because of the difficulty of avoiding run-off, and the frequency of application was increased. The plots in this experiment were free from chlorosis at the beginning of the period, and all of them later exhibited more or less yellowing. The amount of water applied artificially, combined with the natural precipitation, did not total an ex-

cessive amount, except possibly in plot D. This experiment was carried on in a section of the nursery in which the disease did not prove to be prevalent, and little chlorosis occurred in any of the plots. The entire number of yellow seedlings shows an increase with increased watering through all four plots for the last three counts and a somewhat less marked but similar relation for the earlier counts. The magnitude of the difference is, however, not sufficient to permit positive conclusions. Whether the apparent effect of the watering in increasing chlorosis was mostly due to the solutes in the excess water, to cooling the soil, or to hindering aeration, it is not possible to say. That the entire effect of the watering should have been due to disturbance of aeration, or temperature, seems scarcely possible in the cases of plots B and C, which received relatively little artificial watering. These plots did not seem excessively wet, but the soil of plot D was sufficiently wet to permit the development of moss—abnormally wet for this nursery.

TABLE II.—*Effects of different amounts of artificial watering on chlorosis in 4- to 5-month-old Douglas fir seedlings*

	Plot A, unwatered.[b]	Plot B, lightly watered.[b]	Plot C, moderately watered.[b]	Plot D heavily watered.[b]
1917.				
Rainfall and artificial watering (in inches):				
First half of August	Traces.	0.54 (3)	1.11 (3)	1.65 (3)
Last half of August	0.25 (3)	.34 (4)	.43 (4)	.33 (4)
First half of September	1.07 (6)	1.34 (7)	1.61 (7)	1.91 (7)
Last half of September	.71 (2)	1.07 (6)	1.43 (6)	1.83 (6)
First half of October		.18 (2)	.36 (2)	.56 (2)
Total, Aug. 2 to Oct. 6	2.03 (11)	3.47 (22)	4.94 (22)	6.48 (22)
Percentage of seedlings found chlorotic:[a]				
Sept. 1	7.8	11.8	10.7	17.9
Sept. 13	6.1	7.5	7.0	14.7
Sept. 22	1.7	4.3	5.1	8.4
Oct. 2	.4	2.2	2.9	4.8
Oct. 22	.4	2.2	2.6	4.0

[a] Two square feet counted in each plot. Number of seedlings per square foot at beginning of test: Plot A, 241; B, 244; C, 363; D, 278.
[b] Figures in parenthesis indicate total number of days on which rain or artificial watering occurred.

A pathologic condition may be encountered in certain conifers growing in wet situations. This condition would be unfavorable and therefore would result in subnormal vigor and growth of the plants subjected to such abnormal conditions. In studying hypertrophied lenticels at the Bessey Nursery, near Halsey, Nebr., one of the writers (*8*) conducted an experiment in heavy watering, in which irrigations approximately equivalent to 2.2 inches of rainfall were repeated 17 times during a period of three months on western yellow pine transplants grown two years in the seed bed and one year in the transplant bed. Considerable chlorosis appeared in the heavily watered beds, the plants of which were originally thrifty and free of chlorosis, while the controls remained nonchlorotic. There is also a possibility of a lack of proper aeration of the soil and of

oxygen hunger as a very probable and effective stimulus in inducing chlorosis in a mesophyte like Douglas fir in an excessively wet soil.

SPRAYING WITH FERROUS SULPHATE

Spraying with ferrous sulphate was tested on western yellow pine and Douglas fir. The first tests were on seedlings of the former species approximately 14 months old. Plots 4 by 10 feet were laid out, series I in beds in which chlorosis was not serious, and series II in beds in which it was very prevalent. The two plots in each were adjacent and parallel. Care was taken to choose plots as nearly as possible identical in vigor, number of seedlings per square foot, and amount of chlorosis. One of the plots in each series was sprayed with iron-sulphate solution at the rate of 2 gm. of sulphate per 100 cc. of water, and the other was given an

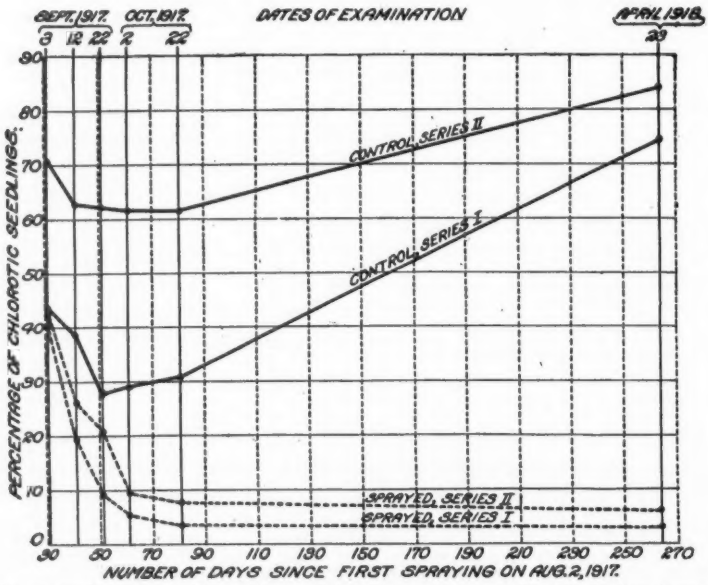
SEPT. 1917.
OCT. 1917.
APRIL 1918.
DATES OF EXAMINATION
3 12 22 2 22 29
PERCENTAGE OF CHLOROTIC SEEDLINGS.
90 80 70 60 50 40 30 20 10 0
CONTROL, SERIES II
CONTROL, SERIES I
SPRAYED, SERIES II
SPRAYED, SERIES I
30 50 70 90 110 130 150 170 190 210 230 250 270
NUMBER OF DAYS SINCE FIRST SPRAYING ON AUG. 2, 1917.

FIG. 1.—Graph showing the effect of a ferrous sulphate spray treatment on chlorosis in seedlings of western yellow pine 14 to 18 months old.

equal quantity of water only and was used as a control. The spraying was done with a hand-spray pump and was begun on August 2, 1917. In each case the plot selected for the treatment appeared slightly more chlorotic than the control at the time of the first treatment. On August 24, after two sprayings, it was evident that chlorosis had been decreased but that chemical injury to the youngest growth had resulted from the treatment. This injury is somewhat surprising, in view of the successful use of 8 per cent solutions on pineapple (*12*). The difference in results may, of course, be due to difference in the localization of the solution on

the surfaces of the two plants. Conifers are very difficult to coat evenly with a spray. Also the fact that there had been practically no rain from the first treatment to the time the injury was observed may have been responsible for the degree of injury by the 2 per cent solution. In a region of heavier rainfall this solution, or even a stronger one, might be entirely harmless to conifers. The treatments were continued, but with a 1 per cent solution at the rate of only 0.1 of a pint, containing approximately 0.47 gm. of ferrous sulphate per square foot of seed bed. Sprayings with this weaker solution were made on August 24, September 3, September 12, September 22, and October 2; and the seedlings on sample areas were counted and classified as to the degree of chlorosis on different dates in September and October, and again in April of the following year.

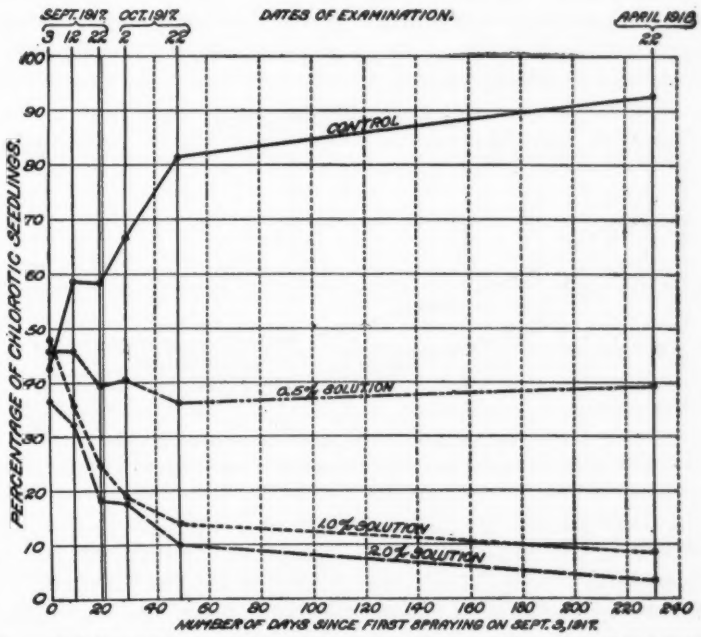

FIG. 2.—Graph showing the effect of a ferrous sulphate spray treatment on chlorosis in seedlings of western yellow pine 2 to 5 months old.

The results are shown graphically in figure 1. Decided inprovement in the color of the sprayed plots during the period covered by the counts is indicated by the data. The undiminished persistence of the good effect through the winter, a total of 6½ months after the last spraying, and the smaller percentage of winterkilled seedlings in the sprayed plots (Table I) are worthy of note.

At the time the first counts were made on the older seedlings (September 3) plots of the same size were also laid out in beds of both western yellow pine and Douglas fir of the current year's sowing and were therefore

about 3 months old. The results with the young western yellow pine (fig. 2) are more striking than those with the older stock. Autumn losses, presumably due to late damping-off, were not affected by the treatments; but winterkilling was entirely prevented (Table I). The heaviest treatment seemed to give better results than the lighter ones, so far as correcting chlorosis was concerned, both at the fall and the succeeding spring examinations, but resulted after the third treatment in the blackening of some of the leaves. The chemical injury was even more marked at the time of the spring examination, when practically every seedling in all the western yellow pine plots treated with the 2 per cent solution showed chemical injury, whereas the plots treated with the weaker solution showed none.

With young Douglas fir (fig. 3) the amount of chlorosis initially present was less, and the untreated seedlings as well as the treated improved in color during the course of the experiment. In so far as chlorosis is corrected, the results are similar to those secured with western yellow

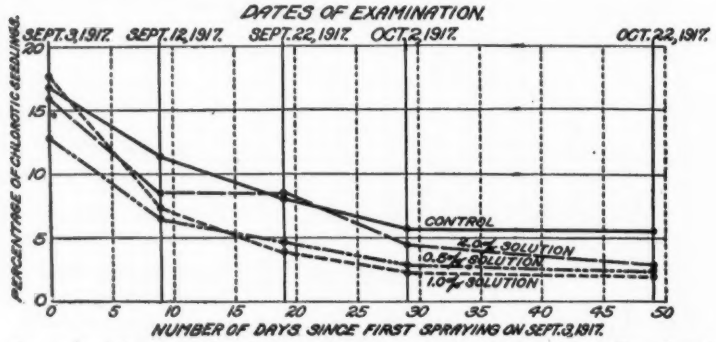

FIG. 3.—Graph showing the effect of a ferrous sulphate spray treatment on chlorosis in seedlings of Douglas fir 2 to 5 months old.

pine.. On Douglas fir, however, the heaviest treatment was no more effective against chlorosis than the lightest; the intermediate gave the best results. In view of this and the injury to western yellow pine from the strongest solution, it appears that only the intermediate strength (1 per cent) should be used on conifers, at least if repeated spraying is practiced.

Though the total area counted in all the spraying experiments with first-year seedlings was small—12 square feet in the treated plots and 6 square feet in the controls—the data obtained from the counts show on the whole such consistent and decided improvement in the sprayed plots as to leave no reasonable doubt about the therapeutic value of the treatment for western yellow pine. Observations on the entire area of the western yellow pine experimental plots (200 square feet treated and 120 square feet in the controls) indicate that the sample areas on which the counts were made were reasonably representative of the entire plots.

The contrast between the treated and untreated plots of western yellow pine at the close of the experiments was very strong throughout.

No attempt was made to exclude the ferrous sulphate from the roots. In view of the high absorptive capacity for iron sulphate of the calcareous soil with which Sachs worked (*19*, *20*) and the prompt reaction (fig. 2) following the small amount of the sulphate added by the writers in the 1 per cent solution treatments on the younger western yellow pine seedlings (fig. 2 and Table I), it is believed that the effect of the iron-sulphate spraying was due to the entrance of traces of iron into the leaves, presumably mostly through the stomata, though Molisch (*14*) reports it as entering through the cuticle.

Forest officers report that 1 per cent ferrous sulphate sprayings begun in April at the Morton Nursery corrected chlorosis in 2-year-old seedlings of both jack pine (*Pinus banksiana*) and western yellow pine by June. Scotch pine did not show chlorosis; jack pine showed it most. The control of the yellowing was not absolute but was practically complete by the end of July. The iron-sulphate spray treatment is considered so successful that it has now been put into general use on all the jack pine and western yellow pine seed beds at the Morton Nursery.

VALUE OF THE EXPERIMENTS

It appears from the literature cited in the introduction that on soils containing considerable calcium carbonate there often occurs a chlorosis which can be corrected by the addition of iron in soluble form to either the roots or the leaves. The trouble-making capacity of the calcium carbonate, though not always in evidence, appears to be more or less specific. Other calcium salts and other carbonates do not seem equally effective as causes of chlorosis. It is reasonable to suppose, in view, among other things, of the precipitation of iron in alkaline solutions, the apparent substitution of iron for calcium in soil (*15*), and the nonavailability of colloidal iron (*7*, *11*) that the trouble was chiefly due to the lack of dissolved iron in the water of certain calcareous soils. However, in the lime soil it might conceivably be that the balance of the solution for plants which are not distinctly calciphile is so disturbed as to make more than the usual amount of iron necessary to maintain the plants in normal health on such soils. A further complication is the fact that the distribution of chlorosis in different parts of the same plant is sometimes such as to indicate that at least part of the difficulty may be due to derangements in conduction instead of or in addition to absorption failures. Furthermore, physiologists are not all ready to agree that the lack of green is really a symptom of a specific iron hunger, even in cases in which the remedial value of iron addition is demonstrated. The writers' results have made no addition to the knowledge of the immediate cause of the chlorosis or the way in which the addition of iron works in correcting it. These complications are mentioned merely to show that fundamental

work on chlorosis lies in the domain of the biochemist rather than of the pathologist or the forester.

The immediately practical applications are fortunately simpler. The writers have added three gymnosperms to the considerable list of angiosperms in which chlorosis can be relieved by spraying ferrous sulphate on the surfaces of the leaves. While the best way to avoid chlorosis in coniferous nurseries is probably to avoid soils containing any considerable quantities of calcium carbonate, an entirely practicable method of treatment is offered by which chlorosis can apparently be relieved in coniferous nurseries on lime soils. At the rate at which the experimental spraying was done, using the 1 per cent solution, which on the whole gave the best results, 1 pound of the relatively cheap ferrous sulphate is sufficient for over 900 square feet of bed. While with larger stock more material would be required, the process would still be relatively cheap. Johnson (*10*), using a solution eight times as strong, reported the total cost of spraying pineapples as $0.60 per acre for each spraying. In a business as intensive as that of raising coniferous nursery stock such a cost item would be almost negligible.

RELATION BETWEEN CHLOROSIS AND GROWTH

Observations through several seasons at the Pocatello Nursery have indicated a relation between chlorosis and poor growth. In order to secure data on this relationship the seedlings in the control plots whose counts are given in figure 1 were classified by their apparent vigor of growth as well as according to their chlorotic condition. The counts showed for the first series that 23 per cent of the seedlings classed as vigorous were chlorotic, while 42 per cent of the weak seedlings were in the chlorotic class. For the second series the difference was about the same, 46 per cent of the vigorous seedlings being chlorotic against the very high proportion of 73 per cent among the seedlings classed as weak. In an effort to put this relationship on a more exact basis, specimens were selected from each class and subclass of seedlings of which a sufficient number were available to give a reasonable numerical basis, and measurements of roots, stems, and leaves were made.

METHODS OF SECURING MEASUREMENTS

The seedlings taken were selected by a process of mechanical elimination, every fifth seedling being chosen in most of the cases, so that they are believed to be representative of the groups from which they came. The leaf surface values were obtained by a method which does not pretend to give the absolute surface accurately, but which is believed to give sufficiently accurate relative values to permit a comparison of the different groups of plants.

The surfaces of the primary and secondary leaves of western yellow pine were determined separately on account of their different shapes.

The primary leaves are approximately semicircular in cross section, and for the purpose of obtaining a comparative surface value were considered as halves of cylinders having a radius equal to the thickness of the leaf midway between the base and the tip, with the length equal to the length of the leaf. The perimeter of the cross section at this point was taken as $\pi R+2R$—that is, the sum of the lengths of the curved and the flat margins of the cross section. The surface of the leaf was taken as $S=L(\pi R+2R)$, in which L equals the length of the leaf. A sufficient number of primary and secondary leaves from each plant were measured to allow averaging (usually from 25 to 100, depending on the number per plant). The total primary leaf surface for the plant was obtained by multiplying the surface of the average leaf by the entire number of primary leaves. The secondary leaves were in most cases in fascicles of three, and their cross-sectional shape may be diagrammed as in figure 4. The same assumptions were made in this case as in the case of the primary leaves, the leaf being taken as an exact third of a cylinder with the radius equal to the thickness of the leaf midway between the base and the tip, and the surface calculated by the formula $S=L\left(\frac{2\pi R}{3}+2R\right)$. This formula appears to be more nearly correct than a paraboloid formula, and it is believed that it offers a better basis for comparing the leaf surface of one group of plants with that of another than would be given by statements of the average number, length, breadth, and thickness of the leaves.

FIG. 4.—Cross-sectional shape of fascicle of three secondary leaves of western yellow pine.

INTERPRETATION OF THE MEASUREMENTS

From Tables III and IV it appears that the height and the weight of the tops, the length and the weight of the roots, the diameter of the stems at the root collar, the length and thickness of the secondary leaves, and the average total leaf surface of the plants was less for chlorotic plants than for green seedlings of the same vigor class and that terminal bud formation was most common and most pronounced in the most vigorous plants. The data indicate that the failure to form buds is related to a general lack of vigor, which in many cases is associated with chlorosis. The adverse effects of chlorosis on terminal bud formation and development is significant in connection with the high winter mortality of the strongly chlorotic seedlings.

The small size of the different parts of the plants in the chlorotic seedlings, as compared with the green seedlings, is, on the whole, fairly uniform. Two exceptions to this are, however, noteworthy. In Table III it appears that the roots of the chlorotic plants are nearly as long

as those of the green plants. However, the weight of the roots was decidedly less in the chlorotic than in the green plants. This agrees with the field observations, indicating an association between chlorosis and a deficiency of fibrous lateral roots. It will be noted that the strongly chlorotic plants in the vigorous class had a root weight considerably less than that of the green plants in the weaker class. While the roots of these plants were also somewhat shorter, the weight difference was distinctly greater.

The other lack of parallelism between increased chlorosis and decreased growth is in the primary leaves. These were nearly as well developed in the chlorotic plants as in the green plants. This is considered significant as indicating that the plants which were decidedly chlorotic and lacking in vigor during the second season were not originally very different in their growth rate from the others. This relationship is most easily seen in the three columns under "Relative leaf surface" in Table IV.

TABLE III.—*Root, top, and terminal bud development of the different type classes of 2-year-old seedlings*

Type classes.	Number of seedlings.	Average diameter of stem at root collar.	Tops.		Roots.		Average total weight of seedlings.	Terminal buds.		
			Average length.	Average weight.	Average length.	Average weight.		Percentage of seedlings forming terminal buds.	Average length.	Average diameter.
UNTREATED WESTERN YELLOW PINE [a]										
		Inches.	*Inches.*	*Gm.*	*Inches.*	*Gm.*	*Gm.*		*Inches.*	*Inches.*
Vigorous, green	100	0.075	2.2	1.40	11.7	0.57	1.97	9	0.33	0.16
Vigorous, slightly chlorotic	95	.065	1.7	.77	9.7	.33	1.11	2	.23	.12
Vigorous, strongly chlorotic	22	.062	1.6	.52	8.6	.20	.72	0	.....	.....
Weak, green	100	.060	1.6	.54	9.6	.26	.80	0	.....	.....
Weak, slightly chlorotic	100	.058	1.4	.35	9.3	.18	.52	0	.....	.....
Weak, strongly chlorotic	100	.045	1.2	.22	9.6	.12	.34	0	.....	.....
UNTREATED DOUGLAS FIR [a]										
Green	50	.046	2.8	.34	9.6	.15	.50	100	.15	.08
Chlorotic	50	.038	2.3	.22	8.2	.08	.30	86	.10	.04

[a] The number of chlorotic plants in the treated plots at the end of the season was insufficient to serve as a basis for measurement.

TABLE IV.—*Leaf development of the different type classes of 2-year-old seedlings*

UNTREATED WESTERN YELLOW PINE[a]

Type class.	Number of seedlings.	Primary leaves.					Secondary leaves.				Average total leaf surface per plant.	Relative leaf surface.[b]		
		Average number per plant.	Average length.	Average thickness.	Average leaf surface per plant.	Percentage of seedlings bearing secondary leaves.	Average number per plant.	Average length.	Average thickness.	Average leaf surface per plant.		Primary leaves.	Secondary leaves.	Total.
			Inches.	*Inches.*	*Square inches.*			*Inches.*	*Inches.*	*Square inches.*	*Square inches.*			
Vigorous, green	100	37.7	1.05	0.016	3.27	100	32.1	2.61	0.023	7.89	11.15	100	100	100
Vigorous, slightly chlorotic	100	40.8	.80	.012	2.02	100	29.9	1.82	.015	3.34	5.36	62	42	48
Vigorous, strongly chlorotic	22	42.2	.83	.014	2.52	100	25.2	1.63	.015	2.52	5.05	77	32	45
Weak, green	100	31.2	.85	.013	1.77	99	23.4	1.45	.015	2.08	3.86	54	26	36
Weak, slightly chlorotic	102	46.4	.67	.013	2.08	68	18.1	1.09	.017	1.37	3.45	64	17	31
Weak, strongly chlorotic	100	38.1	.60	.013	1.41	43	13.7	1.05	.015	.88	2.29	43	11	21

UNTREATED DOUGLAS FIR[a]

Green	50	95.1	0.50	0.010	2.44	.....	.....	.....	.....	.....	2.44	100	.....	100
Chlorotic	50	83.0	.45	.007	1.34	.....	.....	.....	.....	.....	1.34	55	.....	55

[a] The number of chlorotic plants in the treated plots at the end of the season was insufficient to serve as a basis for measurements.
[b] Untreated "vigorous green" leaves taken as 100.

This difference between the first and second season's growth of the same plants is thought to have some bearing on the character of the association between chlorosis and lack of vigor. Three possible explanations of this association present themselves: (1) A general lack of vigor may predispose to chlorosis; (2) the conditions which cause reduced vigor at this nursery may also favor chlorosis, so that the two phenomena are coordinate effects of the same set of conditions; (3) the poor growth of chlorotic plants may be a result of the chlorotic condition.

The first of these possibilities has little to recommend it from the theoretical standpoint, in so far as vigor is judged by the growth rate of the tops. Sachs (*19*) finds iron-hunger chlorosis especially common in rapidly growing shoots. The evidence in Tables III and IV that the chlorotic seedlings were not seriously deficient in growth of tops at the beginning of their second season tends further to discredit this first suggested explanation. Such difference in the primary leaf system as did exist between the different subclasses was more likely the effect of chlorosis during the preceding year than the cause of chlorosis during the current season. However, the root weights are of some interest. That poor root development may predispose to chlorosis is entirely probable. In a soil deficient in available iron, a plant with little root surface would presumably be especially liable to iron hunger.

The second and third explanations are both believed to apply in part to the obvious association of chlorosis and poor development. Lack of balance of soil solution around the roots of the plant sufficient to interfere seriously with the chlorophyll-forming function might easily interfere more or less with some of the other processes in the plant to an extent sufficient to decrease growth rate. Furthermore, the shortage of chlorophyll and consequent decreased ability to synthesize carbohydrates would very naturally result in decreased growth of at least some parts of the plant. It is, therefore, the belief of the writers that poor development of roots (but not of tops) is probably a contributory cause of chlorosis, that both chlorosis and poor development of the whole plant may in part be parallel and independent results of excessive lime, and that chlorosis is almost certain to result in a still further decrease in growth. A circular relation, therefore, seems to obtain.

The data on Douglas fir in Tables III and IV indicate that with this species, as with the western yellow pine, there is a decided difference in growth between green and chlorotic seedlings. With this species as with the other, the weight of the roots of the chlorotic seedlings is much more deficient than the length. From the data it is not possible to determine separately the first and second year's growth, as was possible to a certain extent in the western yellow pine. The deficient terminal bud production and development on the part of the chlorotic plants is as evident in Douglas fir as in western yellow pine.

A condition associated with chlorosis in Douglas fir which does not appear in the measurements is its abnormally prompt loss of turgor on the cutting off of the water supply. The leaves of chlorotic seedlings wilted so quickly after the plants were taken up that measurements of the width of the leaves could not have been accurately made for this species. Another difference not shown by the measurements is in the color of the terminal buds formed. The terminal buds of normal Douglas fir are a reddish brown, while those of the chlorotic seedlings vary from a light brown to a brown.

No relation between the growth rate and the artificial supply of iron was evident from an examination of the beds. As the treatments were not begun until the latter part of the growing season, no material effect was to be expected.

SUMMARY

Chlorosis has been the most serious problem encountered in the successful production of coniferous nursery stock at a nursery in southern Idaho. The disease affects all coniferous species grown in this nursery. With chlorosis were associated poor growth of roots, stems, and leaves, failure to form normal terminal buds, and susceptibility to winter injury.

The importance of excessive soil moisture as a cause of chlorosis has not been definitely determined. Preliminary experiments indicate, however, that it is relatively unimportant.

Chlorosis in western yellow pine at the Pocatello Nursery has been definitely corrected by spraying with ferrous sulphate at 10-day intervals. Similar, though less decisive, results were obtained with Douglas fir. A 1 per cent solution in amounts sufficient to wet the tops thoroughly proved the most satisfactory treatment. A 2 per cent solution ultimately caused chemical injury to practically all the plants. In a region of more frequent rains the stronger solution might be better.

The control of chlorosis in jack pine and western yellow pine at the Morton Nursery in Nebraska by spraying with a 1 per cent solution of ferrous sulphate has given such evidence of success that it has been adopted as a part of the regular nursery practice.

The three soils on which conifers have been found decidedly chlorotic all contain considerable amounts of carbonate and have been formed, in part at least, from limestone. The nursery water supply at Pocatello also contains much calcium bicarbonate. No definite correlation could be found between chlorosis and the amounts of calcium or of carbonate obtained by hydrochloric-acid digestion analysis.

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ROOTING STEMS IN TIMOTHY

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INTRODUCTION

In botanical and agricultural literature there are many references to stolons and rootstocks or rhizomes in timothy. However, the statements made and the terms employed are so confused that it is scarcely possible to determine in any case the specific nature of the phenomenon that occurs. It is by no means clear whether rooting stems above or below ground are referred to; neither is it clear to what extent and under what conditions such stems are actually formed. Some writers have concluded that stolons and rootstocks are varietal characteristics, while others indicate that they are very generally found in timothy. No effort has been made by the writers to find the first mention of stolons or rhizomes in the literature on timothy, but apparently they were not mentioned by botanists or agronomists prior to the time of Linnaeus. In the literature of the nineteenth century, however, there are many references, principally to what are termed stolons; but no detailed information is given regarding them, and consequently there is a very general lack of knowledge of just what they really are, or as a matter of fact that they actually exist.

In connection with their timothy breeding investigations, the writers have had the opportunity to study the timothy plant closely, and they have devoted some attention to the rooting stems, which it sometimes produces. The results of these studies it is hoped will clear up the subject somewhat. Most of the data upon which this paper is based were obtained at the Timothy Breeding Station, which is conducted cooperatively by the United States Department of Agriculture and the Ohio Agricultural Experiment Station, at Elyria, Ohio.

TWO KINDS OF UNDERGROUND ROOTING STEMS

In June, 1918, some timothy plants were found growing in a field where timothy stubble had been plowed under the previous fall. These plants on casual observation had the appearance of plants which had grown from seed, but a close examination disclosed the fact that many of them were attached by underground stems to the stubble of the old plants that were turned under. The finding of these underground stems led to further search for plants possessing them and to critical studies regarding their formation. Abundant material was available at the station in the fall of 1918 and in the summer and fall of 1919 in

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fields where timothy stubble and plants had been plowed under at different times of the year.

From their investigations the writers found that underground rooting stems in timothy are of at least two kinds and that each develops in a different way. One type of underground stem is that illustrated in Plate 39, A. This type develops frequently when timothy stubble or plants are plowed under in the summer or early fall. It is the normal thing in timothy for the bud that forms the new shoot to develop from a node below one of the enlarged internodes at the base of an old culm. This is the way the timothy plant reproduces itself vegetatively. During the early growth of the shoot the nodes from which the leaves arise are close together. When the shoot grows in length to form a culm with a spike, only about six of the upper internodes elongate. The total length of the 10 to 20 unelongated internodes at the base of the culm ordinarily does not exceed 0.4 inch. Sometimes, however, it is somewhat longer. From the basal nodes, the root system of the new plant is produced.

While the foregoing is what takes place normally, the development of the new shoots may be modified appreciably by external conditions. When timothy stubble or plants that have passed the seedling stage are plowed under, or are similarly covered with soil, buds that make the new shoots start development in the normal way, usually only one bud on a stem. But the young shoot, instead of rooting where it is formed, almost immediately adjacent the mother plant, grows toward the light. In doing so the internodes at or near the base of the new shoot, sometimes only one, usually two or more, elongate, thus pushing it up to the surface in a nearly vertical direction. In many cases small fibrous roots develop from the nodes between these elongated basal internodes. It is in this way that undergound stems of rootstock-like appearance are formed. The length of the stem produced by the elongation of the basal internodes and the number of internodes involved depend to a very large extent on the depth to which the old culms are covered with soil. Some have been found having eight internodes, and some with a total length of 5.3 inches. Ordinarily these stems do not extend entirely up to the surface of the soil. An occasional shoot has been observed with its crown 3 inches below the surface, although the crowns are usually much nearer the surface than this. When produced under normal conditions, the crown of the young shoot is at the surface of the soil. The varying depth at which the crowns of the shoots attached to underground stems occur may be influenced by the extent of the leaf growth while it is still beneath the surface. The elongation of the basal internodes, together with the growth that takes place in the leaves, brings the tips of the leaves to the surface. The shoots with the greatest leaf development probably reach the surface with the least elongation of the basal internodes, other conditions being equal. This may explain

why some shoots have their crowns rarther beneath the surface than others, even though the buds from which they were produced were covered to the same depth with soil.

Root systems develop from the crown of all timothy shoots having underground stems, and each shoot is soon capable of continuing its growth independently of the mother plant. On a typical plant, selected in November, 1919, from a field in which timothy had been plowed under one year previously, the underground stem connecting the new plant with the parent plant was partly decayed and disintegrated, showing that the plant no longer had any vital connection with the stem from which it originated.

Underground stems of the same type can be induced by placing soil to a sufficient depth about the base of a growing timothy plant. An underground stem which has developed in this way is shown in Plate 39, B. The plant illustrated originated from a seed sown in the spring of 1919. In the following summer soil was placed about the plant to the point indicated by *x* to the right of the figure. The shoot on the left grew from a bud at the base of a culm of the parent plant. The underground stem that attached the new shoot to the mother plant was 1 inch long and was composed of a single elongated internode. The crown of the shoot was ½ inch below the surface of the soil which surrounded it.

The second type of underground stem is found where timothy plants with growing culms are covered with soil, as by plowing. Buds that sometimes form on the culms of these plants frequently develop into shoots and ultimately into independent plants, and the culms themselves become underground rooting stems. This type is illustrated in Plate 40, A. That the stem *a* had developed as a culm before it was plowed under is clearly shown by the lower elongated internode, which is enlarged in diameter and which forms what is commonly, but erroneously, termed a bulb. Further evidence that this stem had already developed as an ordinary culm before it was plowed under is found in the dried and partly disintegrated leaf at the second node above the enlarged basal internode. This leaf could hardly have grown to a length of several inches beneath the surface of the soil. In the plant illustrated in Plate 40, A, it was impossible to determine whether the shoot *b*, growing at the end of the stem, originated from the terminal bud of the culm or from a bud at one of the nodes farther back. It will be noted, however, that there is a secondary underground stem *c* arising from the second node above the enlarged basal internode. This is of the type shown in Plate 39. It is rarely that secondary shoots develop at nodes between the elongated internodes of timothy culms growing under ordinary conditions, but when the culms are covered with soil this frequently occurs. A rooting stem such as is shown in Plate 39 and in Plate 40, A, *c*, might have developed in connection with shoot *b* in Plate 40, A, had the culm *a* from which it arises been covered to a sufficient depth with soil.

A careful examination of the scattering timothy plants that appear in a field where a timothy sod has been plowed under leads to the conclusion that many if not most of them have not come from seed directly but have been produced vegetatively from the buried stubble or culms. This fact is important agronomically, especially when it is desired to grow pure strains of timothy for seed on the sod of a former timothy crop.

So far as the writers have been able to find, these two types of underground stems, both rooting or at least both capable of producing roots, are the only types of underground stems produced in timothy.

ABOVE-GROUND ROOTING STEMS

Rooting stems sometimes develop above ground, but they have rarely been observed at the Timothy Breeding Station. They are apparently formed when weak or decumbent stems come in contact with the soil. Such a stem is shown in Plate 40, B.

Regarding above-ground rooting stems, Witte [1] says (in translation):

> However, in a few cases of dwarf varieties I have noticed that the tufts were less firm, which in turn is due to the fact that the shoots grow out from the axils of the leaves situated higher up on the culm, as, for instance, from the second or third internode above the swollen one. Because in the case of certain varieties at least the lower part of the culm rests on the ground, these shoots easily take root, and in this way we get, as it were, a system of surface runners.

Since the rooting stems that form above ground are apparently but incidentally associated with a decumbent habit of growth, it is very doubtful if they should be regarded as a varietal or strain characteristic. Witte, however, has so regarded them. Ascherson and Graebner [2] have named and described a variety *stoloniferum*, but from their description it is not clear whether their variety includes plants with rooting stems above or below ground, or both. European literature contains so many references to rooting stems in timothy that it is probable there may be forms in Europe which are not found or are at least are not common in this country. On page 36 of his "Om Timotejen," [1] Witte figures a very spreading, short-culmed plant which closely resembles one or more of the forms regarded by some botanists as distinct species of Phleum, which are characterized in general by a decumbent, spreading habit of growth. The influence of these species or forms on timothy may explain why above-ground rooting stems are mentioned so frequently by European botanists and agriculturists. It is quite evident to the writers that underground stems are in no sense a varietal characteristic, since they can be induced without difficulty.

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[1] WITTE, Hernfrid. OM TIMOTEJEN, DESS HISTORIA, ODLING OCH FORMRIKEDOM SAMT OM FÖRÄDLINGSARBETENA MED DETTA VALLGRÄS PÅ SVALÖF. In Sveriges Utsädesför. Tidskr., Årgang 25, Häfte 1, p. 23–44; Häfte 4, p. 143–182; Häfte 5, p. 199–230, 24 fig. 1915. Résumé in German, p. 228–230. Bibliographical footnotes.

[2] ASCHERSON, Paul, and GRAEBNER, Paul. SYNOPSIS DER MITTELEUROPÄISCHEN FLORA. Bd. 2, Abt. 1, p. 143. Leipzig. 1898–1902.

NAMES NEEDED FOR DIFFERENT TYPES OF ROOTING STEMS

The question arises as to what name should be applied to rooting stems in timothy. Stems produced above ground are runners or stolons, according to a commonly accepted definition of these terms. However, the examples given in connection with the published definitions are by no means typical of the phenomenon that occurs in timothy. As for the underground rooting stems, those of the first type discussed in this paper are not essentially different from those found for example in Kentucky bluegrass and red fescue, except that they do not develop normally but are induced by unusual conditions. These stems are formed by the elongation of one or more of the lower internodes of the shoots which normally remain unelongated. The elongation of the internodes is for the purpose of placing the new shoots in a more favorable place for growth and development. This might be said to be the function of all underground stems, except possibly tubers, corms, and the like. But true rhizomes, by which are meant underground stems that root at the nodes and produce stems or leaves progressively, have in addition to this another definite function, that of reproduction. It would appear desirable, therefore, to designate by some specific name the underground rooting stems of timothy and other grasses that develop by the elongation of the basal internodes only under unusual conditions and for the purpose of placing the new shoot in a more advantageous location. Mr. C. V. Piper has suggested for such an organ the name "topothete," a Greek word from topos, a place or location, and thetu, meaning to place. It is evident from a study of the various terms applied to rooting stems and the definitions of these terms that those who formulated them did not appreciate sufficiently the fact that there are at least four distinct types of rooting stems produced by grasses and other plants, two kinds above ground and two kinds underground. Since the existing terms do not meet the needs of the case, the following names are proposed with the hope that they will be given favorable consideration.

DETERMINATE RHIZOME.—An underground stem which is disposed to root at the nodes and from which a single aerial shoot or tuft of shoots is produced; example, Kentucky bluegrass (*Poa pratensis* L.).

INDETERMINATE RHIZOME.—An underground stem, thickened or otherwise, which roots at the nodes and produces aerial shoots progressively; example, quack grass (*Agropyron repens* L.).

DETERMINATE STOLON.—An above-ground stem which roots at the nodes but does not produce aerial shoots progressively. Under this is included lax culms that have come in contact with the soil and have rooted at the nodes; examples, *Paspalum dilatatum* L. and crab grass (*Syntherisma sanguinalis* L.). This type of rooting stem is common in red top (*Agrostis alba* L.) and other species of Agrostis. These grasses, however, also have indeterminate stolons.

INDETERMINATE STOLON.—An above-ground stem which roots at the nodes and from which shoots are produced progressively; examples, Bermuda grass (*Cynodon dactylon* L.) and Rhodes grass (*Chloris gayayna* L.).

It is quite probable that special terms may be needed where it appears desirable to make finer distinctions than are indicated above. However, it is thought that all of the rooting stems, especially those produced by grasses, can logically be designated by the general terms herein proposed. It is deemed advisable to discontinue the use of the term "rootstock," since this term is misleading and has been used by horticulturists in the sense of propagating stock. There appears to be no serious objections to the use of the word "runner" as a synonym of stolon, although it has been used in a more specific sense, as in the case of the strawberry.

SUMMARY

The references in literature to rooting stems in timothy fail to give a description of their nature or functions.

Investigations disclose two quite distinct types of underground rooting stems.

One type develops when the shoot that produces the new plant is covered with soil early in its growth. Some of the unelongated internodes connecting the shoot with the parent plant elongate, thereby pushing the shoot to the surface of the soil. Roots grow from the nodes between the elongated internodes.

A second type of underground rooting stem is produced when timothy plants with growing culms are covered with soil. Buds that sometimes form on the culms of these plants frequently develop into shoots and ultimately into independent plants. The culms then become underground rooting stems.

Many, if not most, of the scattering timothy plants that appear in a field where a timothy sod has been plowed under are produced vegetatively from buried stubbles or culms.

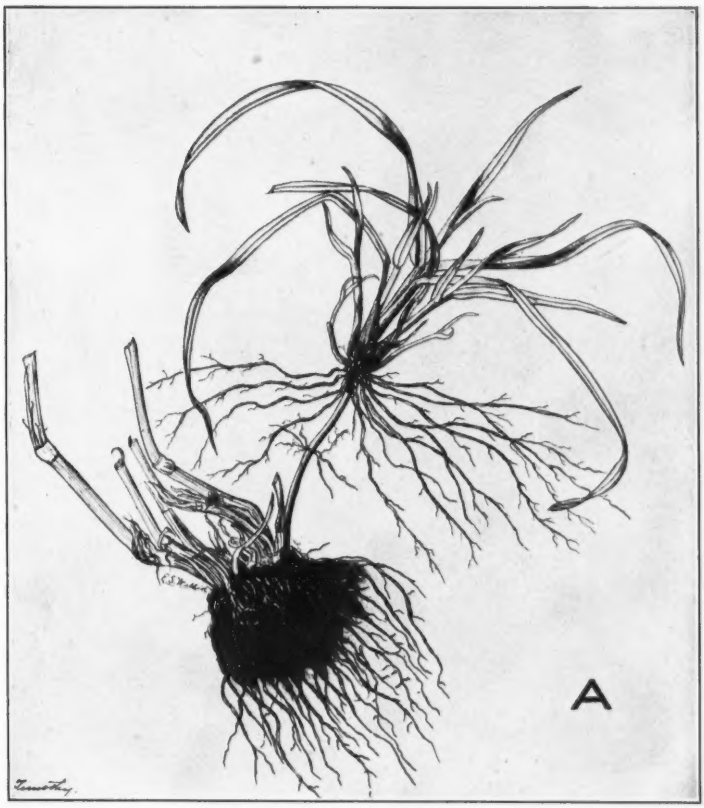
Above-ground rooting stems in timothy are not common in this country. Some botanists have regarded them as a varietal characteristic. It is very doubtful if they should be so regarded. Apparently they are formed most commonly when weak or decumbent stems come in contact with the soil.

Determinate and indeterminate rhizomes and determinate and indeterminate stolons are terms suggested to cover in a general way the types of rooting stems that are found especially in grasses.

PLATE 39

A.—A young timothy plant produced from a bud on a matured culm plowed under. It was pushed to the surface by a rooting stem formed by the elongation of two of its basal internodes.

B.—A rooting stem *b* induced by covering the parent plant *a* with soil to the point *x*.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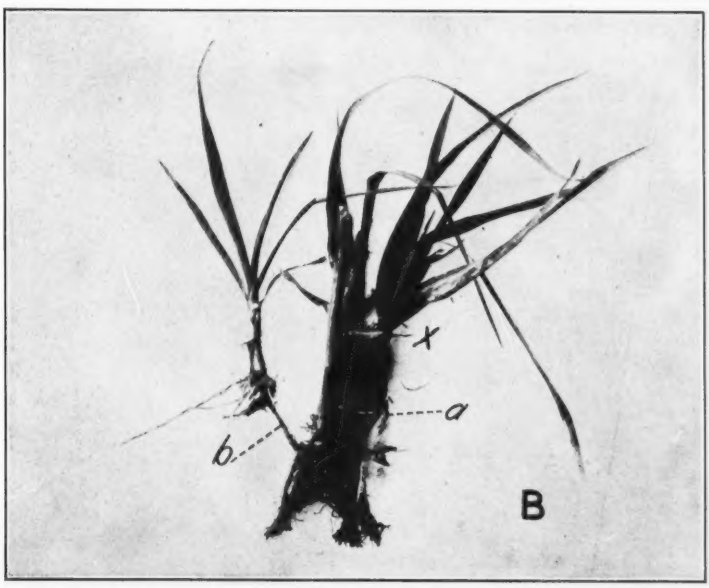
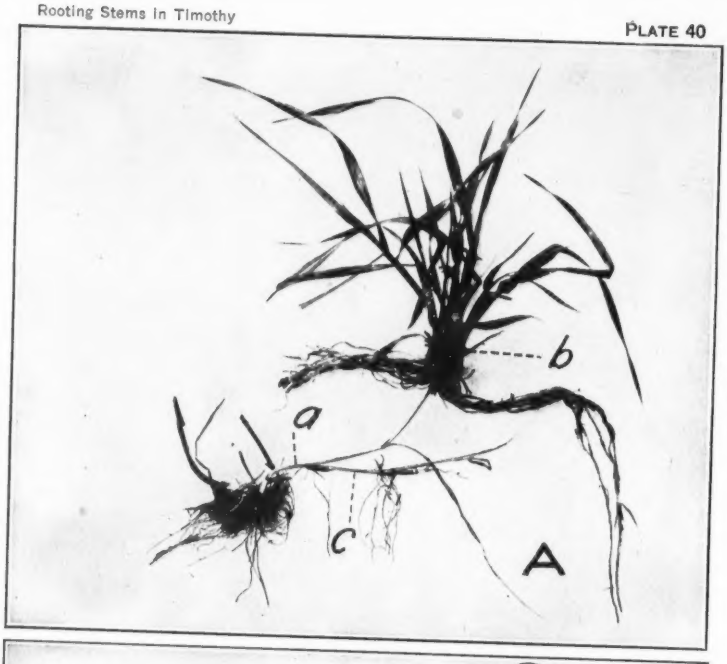

x
a
b
B


a
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A

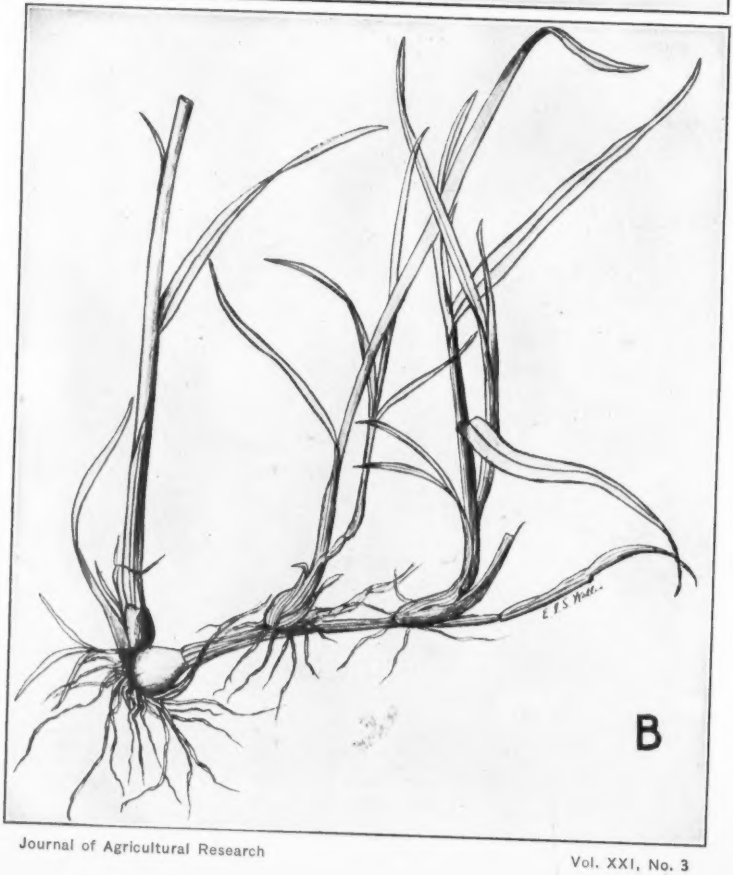
B

PLATE 40

A.—Timothy plants arising from a true culm that was plowed under. Note the roots at the node *a*.

B.—A decumbent culm of timothy functioning as a stolen (after Witte).

COLLAR-ROT OF TOMATO

By F. J. PRITCHARD, *Physiologist*, and W. S. PORTE, *Scientific Assistant, Cotton, Truck, and Forage Crop Disease Investigations, Bureau of Plant Industry, United States Department of Agriculture*

INTRODUCTION

A new disease of tomato seedlings, which takes the form of a rotting and girdling of the stems at the surface of the soil, has for the past three years caused heavy loss in Maryland, New Jersey, and Delaware.

This is chiefly a seed-bed disease. Young, tender plants infected in the seed bed carry the disease to the field. Although field infections may occur also they do not appear to be common. Moreover, the hardened condition of the plants and the relative freedom of the field from the causal parasites make the opportunities for infection less favorable than in the seed bed.

The most prominent symptom of the disease is the dark brown lesions on the stem at the surface of the ground (Pl. 41, A, *a*, *c*) which often encircle the stems, forming a collar. These lesions also occur on other parts of the stem (Pl. 41, A, *b*) but not so frequently as at the soil line. They enlarge and make the affected parts weak and brittle. There is very little infection of the roots.

Diseased plants set in the field are commonly snapped off by the wind at the point of infection. Some recover by forming a callus over the wound, and others outgrow it by forming new roots above the diseased area. Plants which recover are seldom as productive, however, as those which have always been healthy. The estimated loss of the crop from this disease in Delaware in 1919 was 30 per cent.

Rosenbaum [1] attributes the disease to *Macrosporium solani*, and Cook [2] to Rhizoctonia. The writers have isolated from collar-rot material a Verticillium that also readily infects tomato seedlings and causes the typical symptoms of the disease.

The present paper contains the results of inoculation experiments made with this species of verticillium and also with *Macrosporium solani* and *Rhizoctonia solani*.

EXPERIMENTAL WORK

MATERIAL AND METHODS

The Verticillium used in these experiments was isolated from young tomato plants infected by collar-rot in seedbeds in Maryland. The

[1] ROSENBAUM, Joseph. A STEM DISEASE OF TOMATO CAUSED BY MACROSPORIUM SOLANI E. & M. (Abstract.) *In* Phytopathology, v. 10, no. 1, p. 59. 1920.

[2] COOK, Mel. T. THE ALTERNARIA FRUIT ROT AND RHIZOCTONIA STEM ROT OF TOMATOES. (Abstract.) *In* Phytopathology, v. 10, no 1, p 59. 1920.

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culture of *Macrosporium solani* was obtained from L. O. Kunkel and that of *Rhizoctonia solani* from M. Shapovalov. Three strains of *R. solani* were used in the inoculation of 400 plants, but as all three showed about the same degree of infectiousness only one was used in later experiments.

Most of the tomato plants used were 2 to 3 inches high, but some were 5 to 6 inches, and a few 10 to 12 inches in height. All were in good growing condition.

The inoculations were made by placing mycelium from a fresh culture against the stem, at or slightly below the surface of the soil. From cultures of Verticillium both mycelium and spores were used. Usually the epidermis was not injured before applying the inoculum, but in a few experiments it was lightly scratched. To keep the fungus moist until it had time to infect the stems, the soil was thoroughly watered before the plants were inoculated. By placing the fungus between the stem and this moist soil it was kept wet. Usually the plants were left standing in the greenhouse after inoculation, but in a few experiments they were kept in a moist chamber 48 hours.

Repeated inoculation experiments were made with Verticillium, several hundred plants being inoculated and as many more used as controls.

RESULTS OF INOCULATION WITH VERTICILLIUM

Young tender seedlings, such as grow in a seed bed, were very easily infected by this fungus (Pl. 42, A). Plants that had grown slowly and were somewhat woody were less susceptible and not infrequently recovered from the disease. Larger plants 10 to 12 inches high were scarcely susceptible. Infection was obtained on more than 80 per cent of the inoculated plants 1 to 6 inches high, while only an occasional infection, 1 or 2 per cent, occurred on the control plants. The latter was due to the presence of a small amount of the fungus in the greenhouse soil.

Nearly all these infections were obtained without previously injuring the epidermis. In fact, puncturing the epidermis seemed to make little difference, as the fungus was able to penetrate the tissues very easily in either case.

DESCRIPTION OF FUNGUS

Verticillium lycopersici, n. sp.

Dense colonies (Pl. 41, B), at first white and later bluish green, are formed by this fungus on most culture media. The conidiophores are distinctly septate at the base (Pl. 43, D), 70 to 350 μ (occasionally 700 μ or more) in length, verticillately branched. The primary whorls average 5 to 7 in number; the secondary whorls of each branch average 1 to 3. The sterigmata are hyaline, somewhat bottle-shaped (Pl. 43, B, C), and 7.5 to 11.5 μ by 3.5 to 4 μ in size. The conidia (Pl. 43, C, E, F), are globoid to ellipsoid, the globoid being 3.8 to 4.7 μ in diameter, the ellipsoid 3.8 to 4.7 μ by 4 to 5.8 μ in transverse and longitudinal dimensions. They are bluish green on most culture media but yellowish on potato agar. From tips of the sterigmata they are cut off singly but frequently adhere in heads of the so-called Acrostalagmus type.

COMPARATIVE INFECTIOUSNESS OF VERTICILLIUM LYCOPERSICI, MACROSPORIUM SOLANI, AND RHIZOCTONIA SOLANI

Experiments were made to determine the relative infectiousness of these fungi and the difference in type of lesion they produce. Small plants were inoculated as previously described by placing mycelium or mycelium and spores from a fresh culture against the stem at or a little below the soil line.

Table I gives the number and percentage of infections obtained within two to three weeks after the inoculations were made.

TABLE I.—*Results of inoculating tomato seedlings with collar-rot fungi when plants were not placed in a moist chamber*

Fungus.	Epidermis lightly scratched before inoculation.			Epidermis not injured before inoculation.		
	Number of plants inoculated.	Number of plants infected.	Percentage of plants infected.	Number of plants inoculated.	Number of plants infected.	Percentage of plants infected.
Verticillium lycopersici	180	180	100	466	372	80
Macrosporium solani	57	57	100	380	319	84
Rhizoctonia solani	92	47	51	466	72	15
Control				[a] 86	1	1

[a] Number of plants used but not inoculated.

As shown by the table, *Verticillium lycopersici* and *Macrosporium solani* produced a high percentage of infections even when applied to an uninjured epidermis. *Rhizoctonia solani*, on the other hand, produced a much smaller percentage of infections, especially when the epidermis was not injured in the process of inoculation.

In order to determine whether *Rhizoctonia solani* would have produced a higher percentage of infections under more humid conditions another set of inoculation experiments was made in which the plants were kept in a moist chamber 48 hours after inoculation. The results are shown in Table II.

TABLE II.—*Results of inoculating tomato seedlings with collar-rot fungi when plants were kept in a moist chamber 48 hours after inoculation*

Fungus.	Epidermis lightly scratched before inoculation.			Epidermis not injured before inoculation.		
	Number of plants inoculated.	Number of plants infected.	Percentage of plants infected.	Number of plants inoculated.	Number of plants infected.	Percentage of plants infected.
Verticillium lycopersici	6	6	100	21	19	90
Macrosporium solani				27	23	85
Rhizoctonia solani	18	18	100	33	4	12
Control				[a] 15	2	13

[a] Number of plants used but not inoculated.

The percentage of infections by *Rhizoctonia solani* was higher on the scratched series than in the previous experiments but no higher in the unscratched series. *R. solani* seems to require high humidity and a punctured epidermis to cause much infection and is, therefore, a weaker and more limited parasite on tomato than either *Verticillium lycopersici* or *Macrosporium solani*. Moreover, the infections caused by it were more superficial and usually disappeared as the plants became older.

The infected areas produced by *Macrosporium solani* were usually a little darker in color than those made by *Verticillium lycopersici* or *Rhizoctonia solani*, especially on the older seedlings.

In order to determine whether the relative infectiousness of these fungi is the same in soil as when applied to the stems, sterilized soil was mixed with each culture, and in this were planted tomato seeds that had been treated with a solution of bichlorid of mercury 1 to 1,000 to destroy adhering parasites and had been washed in distilled water. The results obtained three weeks after this experiment was started are summarized in Table III.

TABLE III.—*Comparative infectiousness of collar-rot fungi in tomato seed bed*

Fungus.	Number of plants grown.	Number of plants affected by collar-rot.	Percentage of plants affected by collar-rot.
Verticillium lycopersici	567	362	64
Macrosporium solani	420	307	73
Rhizoctonia solani	755	20	3
Control	282	0	0

The results show that *Verticillium lycopersici* and *Macrosporium solani* produced nearly as high percentages of collar-rot infections as in the previous experiments in which the mycelium was placed directly in contact with the stem. Moreover, there was no distinguishable difference in the color or other appearance of the lesions produced by these two fungi. On the contrary, *Rhizoctonia solani* produced very few infections. In fact, under the conditions of this experiment it was not a very active parasite.

The minimum growth temperatures obtained with cultures of these fungi were 1.5° C. for *Macrosporium solani*, 12° for *Verticillium lycopersici*, and 15° for *Rhizoctonia solani*. In cold seed beds *Macrosporium solani* would, therefore, begin to grow before either of the other fungi but would have little advantage over them, as tomato seed will not usually germinate until it reaches a temperature of 14° or 15°. Moreover, *Macrosporium solani* and *Rhizoctonia solani* grow and spread slowly while *Verticillium lycopersici* grows rapidly and spreads readily by means of innumerable spores. In seed bed or field it would therefore probably spread much faster than either of the other fungi.

CROSS INOCULATION

As the potato, which is sometimes grown in rotation with the tomato, and the horse nettle *Solanum carolinense* L., which is a common weed in the Middle Atlantic States, are closely related to the tomato, inoculations of these plants were made with collar-rot fungi. Young shoots were inoculated at the base of the stem with mycelium from a fresh culture, as described in previous experiments. The results are given in Table IV.

TABLE IV.—*Effect of inoculating potato and horse nettle with collar-rot fungi*

Fungus.	Host.	Number of shoots inoculated.	Number of shoots infected.	Percentage of shoots infected.
Macrosporium solani	Potato	43	38	88
Verticillium lycopersici	do	47	25	53
Rhizoctonia solani	do	41	1	2
Control	do	45	0	0
Macrosporium solani	Horse nettle	50	48	96
Verticillium lycopersici	do	50	34	68
Rhizoctonia solani	do	50	5	10
Control	do	50	0	0

The percentage of infections produced on potatoes was higher for *Macrosporium solani* than for *Verticillium lycopersici*. Moreover, the lesions caused by *M. solani* were very prominent (Pl. 42, B), while those caused by *V. lycopersici* (Pl. 44, A) were smaller and more superficial. Only one potato shoot inoculated with *Rhizoctonia solani* was infected. As shown by Edson and Shapovalov,[1] strains of *R. solani* differ markedly in their power of infecting potato plants. Although we used on potato the strain that seemed to give the best results on tomato, it was evidently not a strong potato parasite.

Since all the potato control plants (Pl. 44, B) were healthy, the comparative results obtained with these three fungi are probably reliable.

The results on horse nettle are also of importance, since they show that all three parasites are able to infect this plant. *Macrosporium solani* and *Verticillium lycopersici* (Pl. 45) produced numerous, well-marked lesions. *Rhizoctonia solani* produced only a few, but they suffice to show that it can infect this host.

As the source of this disease is at present chiefly in the seed bed, it can be largely controlled by sterilizing the seed-bed soil. If allowed to go unchecked it may ultimately accumulate in fields in which conditions are favorable for its development. Since its spread will be facilitated by susceptible hosts, both the potato and horse nettle should be kept out of prospective tomato fields in collar-rot infested areas.

[1] EDSON, H. A., and SHAPOVALOV, M. POTATO-STEM LESIONS. *In* Jour. Agr. Research, v. 14, no. 5, p. 213-220, pl. 24-26. 1918.

SUMMARY

Collar-rot of tomatoes has been prevalent in Maryland, New Jersey, and Delaware during the three seasons 1917, 1918, and 1919, destroying many seedlings in the seed bed and newly set plants in the fields.

The girdling of the stem at the surface of the ground characteristic of the disease may be produced by three fungi, *Verticillium lycopersici*, *Macrosporium solani*, and *Rhizoctonia solani*.

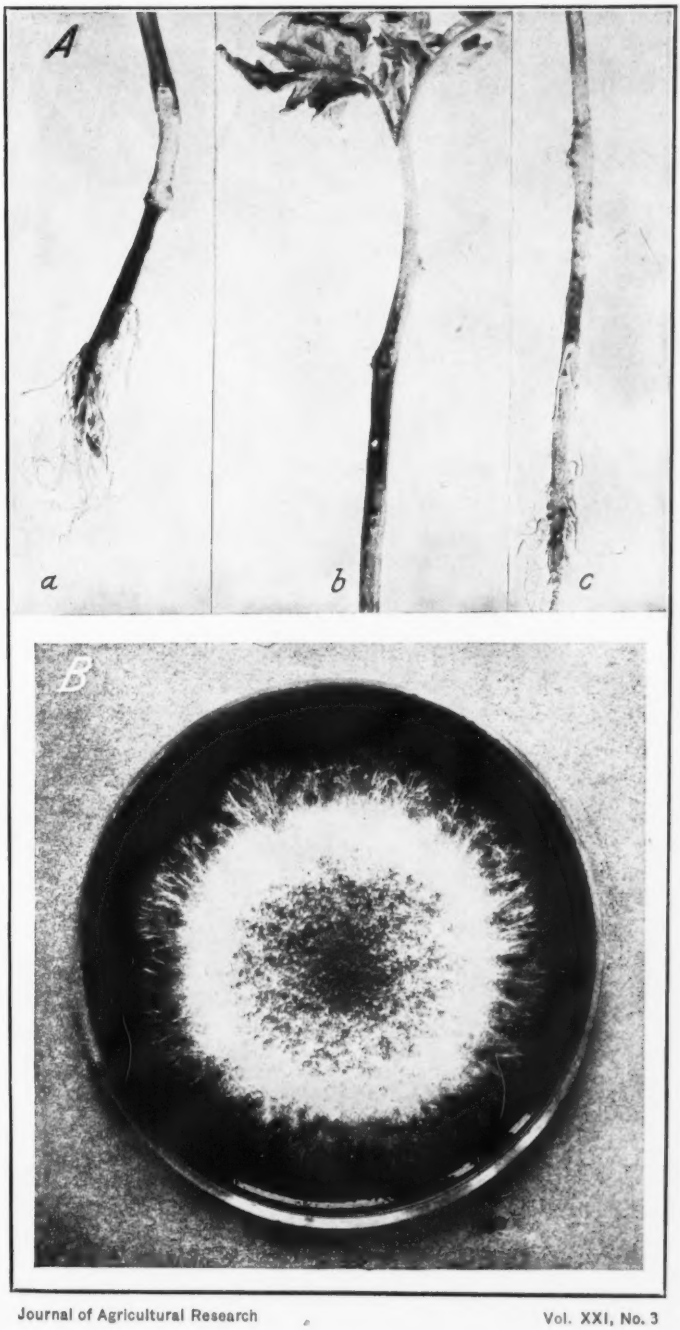
In inoculation experiments with these fungi, made either by applying fresh cultures to uninjured stems or by mixing them with the potted soil, *Verticillium lycopersici* and *Macrosporium solani* infected tomato seedlings about equally well, causing typical lesions on 65 to 100 per cent of the plants used, while Rhizoctonia produced a very few infections of a superficial nature.

On stems of potato and horse nettle all three fungi produced typical collar-rot lesions, but the percentage of infections was much higher for *Verticillium lycopersici* and *Macrosporium solani* than for *Rhizoctonia solani*.

PLATE 41

A.—Tomato seedlings several weeks old affected by collar-rot. Natural infection. *a*, *c*, Infection near surface of soil; *b*, infection near tip of stem.

B.—Typical young colony of *Verticillium lycopersici* on bean agar.


A
a
b
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A
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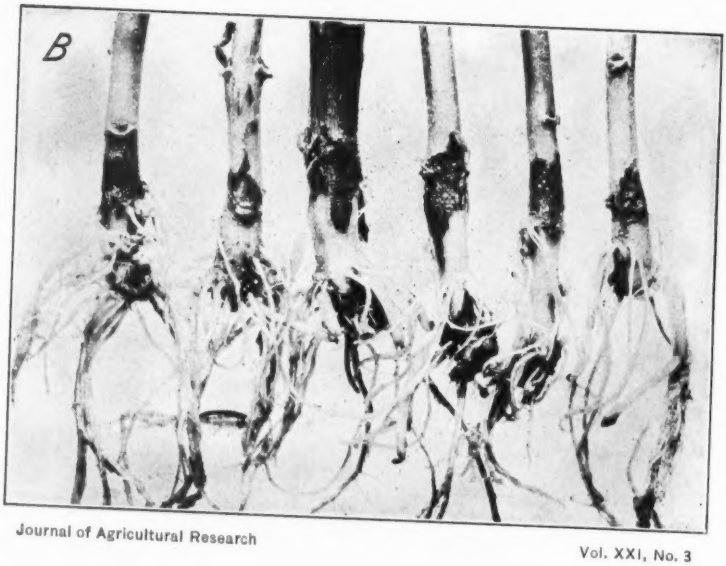
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PLATE 42

A.—Young tomato seedlings 16 days after inoculation with *Verticillium lycopersici*. Epidermis not injured by process of inoculation.

B.—Potato stems infected by *Macrosporium solani*. Inoculated with pure culture without injuring epidermis. Photographed 23 days after inoculation.

PLATE 43

Stages in development of *Verticillium lycopersici:*

A.—Outer end of conidiophore, showing characteristic branching and aggregation of conidia.

B.—End of conidiophore more highly magnified than in A.

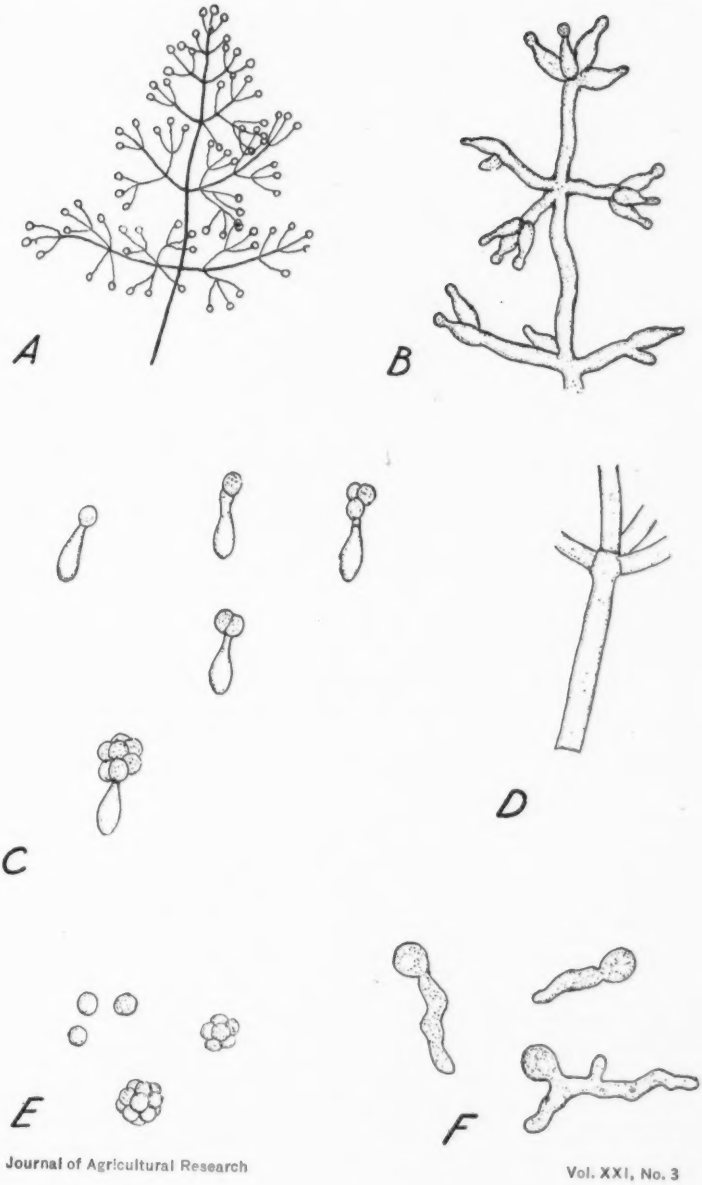
C.—Sterigmata with conidia forming singly at the tips and adhering in heads.

D.—Characteristic septation in lower whorls of conidiophores.

E.—Conidia as seen in air or in water mount. In plate cultures they are found in both separated and aggregated conditions.

F.—Germinating conidia.

All drawings except A were made on a level with the table with camera lucida and Zeiss apochromatic 4-mm. objective and compensating ocular 6 and were reduced one-third.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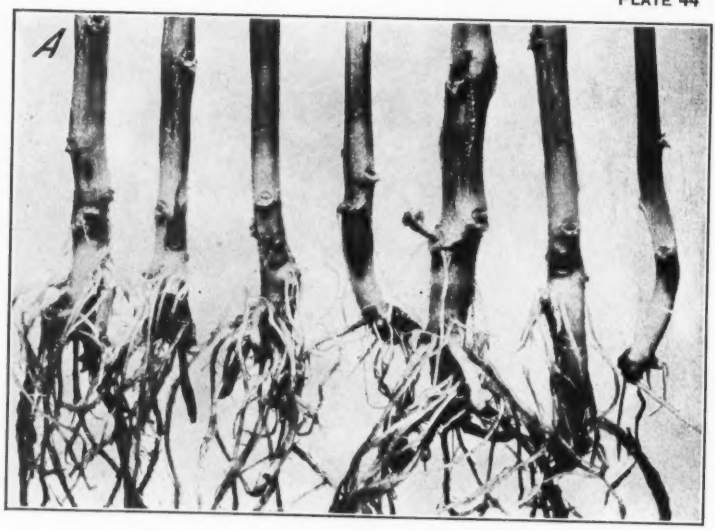
A

B

PLATE 44

A.—Potato stems infected by *Verticillium lycopersici*. Inoculated with pure culture without injuring epidermis. Photographed 23 days after inoculation.

B.—Healthy potato stems used as controls with inoculated stems shown in Plates 42, B, and 44, A. Photographed 23 days after beginning of experiment.

PLATE 45

Horse nettle (*Solanum carolinense*) stems infected by the following fungi: R, *Rhizoctonia solani;* V, *Verticillium lycopersici;* M, *Macrosporium solani;* C, not inoculated (control plants).

Inoculated with pure cultures without injuring epidermis. Photographed 19 days after inoculation.

C
M
V
R

BACTERIAL LEAFSPOT DISEASE OF CELERY

By IVAN C. JAGGER

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Since 1910 an undescribed bacterial leafspot disease of celery has been under observation. A short paper [1] was read at the 1914 meeting of the American Phytopathological Society. The disease has been widely distributed in western and central New York State each season, occurring on all varieties of celery commonly grown, including various strains of Golden Self-Blanching and numerous varieties and strains of "green" celery. Dr. C. H. Coons [2] states that it has been of common occurrence in Michigan during the past few seasons.

The spots are of a rusty brown color, irregularly circular in outline, and rarely exceed 5 mm. in diameter (Pl. 46, 47). They closely resemble the Septoria leafblight spots and can be distinguished with certainty only by the absence of pycnidia, which show as black dots in the Septoria spots. Occasionally the spots are so numerous as to cause the death of many of the older leaves, but usually the injury consists in the disfiguring of the foliage and in a possible reduction in growth of the plants. The disease seems to be confined to the leaf blades, spots seldom, if ever, occurring on the petioles.

Bacteria have been repeatedly isolated and the characteristic spots reproduced by inoculation with pure cultures. In the greenhouse during the winter season the organism, sprayed on uninjured leaves, has repeatedly failed to give infection although inoculations through needle punctures have invariably resulted in characteristic leafspots. Similar inoculations by spraying the organism from pure cultures on uninjured leaves have resulted in abundant infection during the summer season under field conditions.

The causal organism is a short rod, measuring when stained from 3-day agar slants 0.44 to 0.87 μ by 0.87 to 1.74 μ. It has one to several, usually one to three, polar flagella.

In the study of the cultural features the methods given by Smith [3] were followed as far as possible. All observations were made on cultures held at 20° C. Growth on standard nutrient agar is rather rapid, colonies being evident in dilution plates in 48 hours or less; at the end of 3 days surface colonies are 2 to 5 mm. in diameter, grayish white, translucent,

[1] JAGGER, Ivan C. A BACTERIAL LEAF SPOT DISEASE OF CELERY. (Abstract.) *In* Phytopathology, v. 4, no. 6, p. 395. 1914.

[2] COONS, G. H., and NELSON, Ray. THE PLANT DISEASES OF IMPORTANCE IN THE TRANSPORTATION OF FRUITS AND VEGETABLES. Circ. 473-A, Amer. Railway Perishable Freight Assoc., p. 32, fig. 51. 1918.

[3] SMITH, Edwin F. BACTERIA IN RELATION TO PLANT DISEASES. 3 vol. Washington, D. C. 1905-1914.

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shiny, circular, edges entire, flat to slightly raised; buried colonies are 0.2 to 0.5 mm. in diameter, spherical to lens-shaped, white opaque. Growth on agar streaks is similar, cultures several days old usually showing a granular structure and greenish discoloration of the medium. Agar stabs show only slight clouding along the puncture with abundant surface growth. Gelatin is liquefied, usually rapidly, various strains of the organsim, however, showing marked variation in rate of liquefaction. In nutrient broth there is strong turbid clouding, no surface growth, and more or less ropy viscid sediment in 10-day and older cultures. Litmus milk becomes more alkaline, and the casein is usually peptonized without the formation of curd. Fermentation tubes containing tap water, to which has been added 2 per cent peptone and 0.5 per cent sodium chlorid plus 1 per cent, respectively, of lactose, dextrose, saccharose, and glycerin, show no growth in the closed arm and no gas formation. Growth in the open arm is abundant, and litmus paper shows marked production of acid from glucose, less marked production of acid from saccharose, and alkali production from lactose and glycerin. Nitrates are not reduced. There is no growth in Cohn's and Uschinsky's solutions. Growth on cooked potato plugs is abundant and grayish to yellowish white with no indications of diastatic action on the starch.

The group number of the organism is 211.2322033, following the third descriptive card of the Society of American Bacteriologists,[1] adopted in 1907. In the classification recently proposed by the society [2] the organism belongs to the genus Pseudomonas, which is also in accord with the system of Migula. In Smith's [3] system it falls in the genus Bacterium.

Pseudomonas apii, n. sp.

A short rod, 0.44 to 0.87μ by 0.87 to 1.74μ, one to several polar flagella; colonies on nutrient agar grayish white, shiny, circular, edges entire, flat to slightly raised, granular with age; gelatin liquefied, litmus milk becomes more alkaline, casein peptonized without formation of curd; acid formed from glucose and saccharose, alkali from lactose and glycerin, no gas; no growth in closed arm of fermentation tubes; nitrates not reduced; no diastatic action; no growth in Cohn's and Uschinsky's solutions. Group number 211.2322033.

Parasitic in leaves of celery (*Apium graveolens* L.); distribution, New York, Michigan.

Potebnia [4] has described a leafspot of cultivated parsley in Russia caused by *Bacillus petroselina*. The close relationship of parsley and

[1] Society of American Bacteriologists. descriptive chart. Prepared by committee on methods of identification of bacterial species. Endorsed by the Society for general use at the annual meeting, Dec 31, 1907.

[2] Winslow, C., E. A., et al. the families and genera of the bacteria. Final report of the committee of the Society of American bacteriologists on characterization and classification of bacterial types. *In* Jour. Bact., v. 5, no. 3, p. 191–229. 1920. References, p. 226–229.

[3] Smith, Erwin F. op. cit.

[4] Potebnia, A. A. gribnye parasity vysshikh rastenii kharkovsk. i smerzhnykh gubern. (fungous parasites of the higher plants in kharkov and adjacent provinces. Kharkov Obl. Selskokh. Opyt. Sta., No. 1, List. 1/8, p. 1–120, illus. 1915. Review by Michael Shapovalov *in* Phytopathology, v. 6, no. 3, p. 293–295. 1916.

celery suggests the possibility that the celery disease is caused by the same organism. A limited number of inoculations with the celery organism have failed to give infection on parsley. Potebnia states that his organism does not liquefy gelatin, whereas the celery organism invariably causes liquefaction.

During the seasons 1915–1917 spraying, as a means of controlling the disease, was tested at Irondequoit, N. Y. All applications were made with a hand sprayer, maintaining a pressure of 25 to 50 pounds. Care was taken to cover the leaves thoroughly with the spray material. Several rows were sprayed with standard 5–5–50 Bordeaux mixture each season. During the last two seasons comparable rows were sprayed with commercial lime-sulphur solution, testing 32° Beaumé, which was diluted 1 part to 25 parts of water. The first application was made soon after the plants were transplanted from the seed bed to the field and was repeated at intervals of one to two weeks until a few weeks before harvest. In 1915, applications were made on August 9, 21, September 1, 10 and 22; in 1916, on August 12, 19, 28, September 6, 16, 26, and October 6; and in 1917 there were a similar number of applications.

Each season data were taken in October, a few days before harvest. The number of bacterial leafspots were counted on representative plants occupying opposite positions in adjacent sprayed and unsprayed rows. A part of the data is given in Table I. Sets of figures separated by horizontal spaces are for opposite and comparable plants. The number of spots on each leaf is given separately, the leaves being numbered consecutively from the oldest to the youngest fully expanded leaf.

In 1917 Dr. H. W. Dye of the Cornell Agricultural College made three applications of standard 5–5–50 Bordeaux mixture at intervals of about nine days at Williamson, N. Y., to celery which already showed the bacterial leafspot disease. A few days after the last application the number of bacterial leaf spots was counted on 10 sprayed plants and 35 comparable unsprayed plants. The average number of spots per plant was for the sprayed 214 and for the unsprayed 997.

The data presented seem to show conclusively that the disease is very satisfactorily controlled by spraying with Bordeaux mixture but is not controlled with lime-sulphur solution. General appearances of the sprayed and unsprayed rows in the field led in every case to the same conclusion.

TABLE I.—*Number of bacterial leafspots on the leaves of sprayed and unsprayed celery plants*

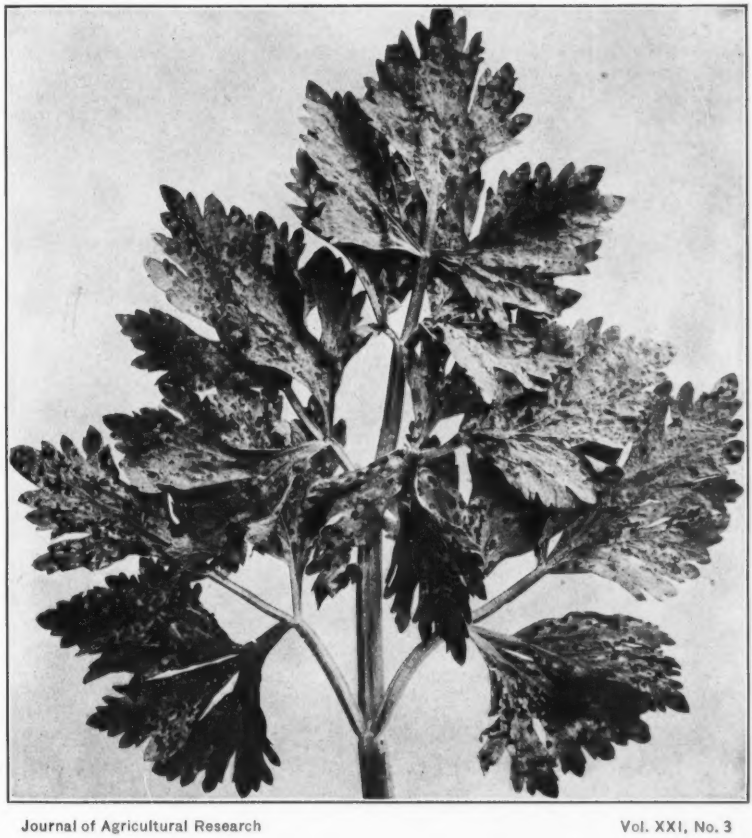
Treatment (spray material applied).	Number of spots on individual leaves, numbered from oldest to youngest—												Total number leaf spots on plant.	Year.
	1	2	3	4	5	6	7	8	9	10	11	12		
Control	98	94	74	62	63	51	10	0	0	0	....	....	452	1915
Bordeaux	2	1	3	0	0	0	0	0	0	0	....	....	6	
Control	195	77	17	16	42	0	0	0	0	0	....	....	347	
Control	425	82	144	60	36	0	0	0	0	0	....	....	747	1915
Bordeaux	64	18	1	5	0	0	0	0	0	0	....	....	88	
Control	475	250	73	93	32	38	0	0	0	0	0	....	961	
Control	147	117	48	32	25	13	4	0	0	0	....	....	386	1915
Bordeaux	6	5	0	0	0	0	0	0	0	0	0	....	11	
Control	233	143	109	30	64	0	0	0	....	....	....	....	579	
Control	68	65	41	23	46	16	4	0	0	0	0	0	263	1916
Lime-sulphur	56	54	56	38	18	11	13	0	0	0	0	....	246	
Control	58	62	32	35	13	2	0	0	0	0	0	....	202	
Bordeaux	0	0	0	0	0	0	0	0	0	0	0	....	0	
Control	83	13	27	64	12	6	15	0	0	0	0	....	220	
Lime-sulphur	33	70	72	82	77	39	32	3	0	0	0	0	408	1916
Control	29	21	44	81	66	42	15	16	0	0	0	0	314	
Bordeaux	1	5	0	0	0	0	0	0	0	0	0	....	6	
Lime-sulphur	90	96	51	48	15	20	56	4	4	0	0	0	384	1917
Control	86	100	145	95	150	96	66	29	16	10	0	0	793	
Bordeaux	1	0	0	0	2	0	0	0	0	0	0	0	3	

SUMMARY

Pseudomonas apii, n. sp., is the cause of a leafspot disease of celery in New York and Michigan. The disease is controlled by spraying with Bordeaux mixture.

PLATE 46

Bacterial leafspots on leaf of Golden Self-Blanching variety of celery.



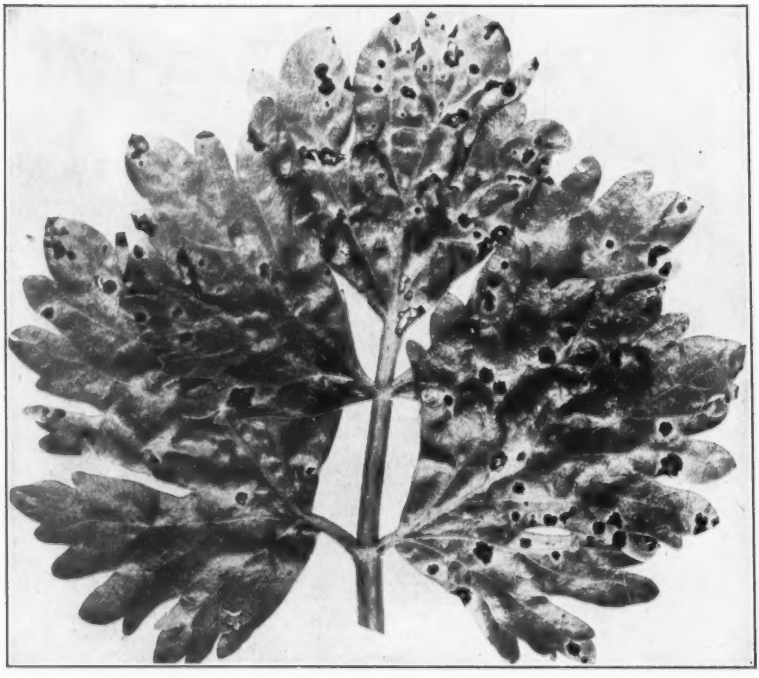


PLATE 47

Bacterial leafspots on leaflet of Golden Self-Blanching variety of celery. Approximately × ⅞.

36731°—21——7